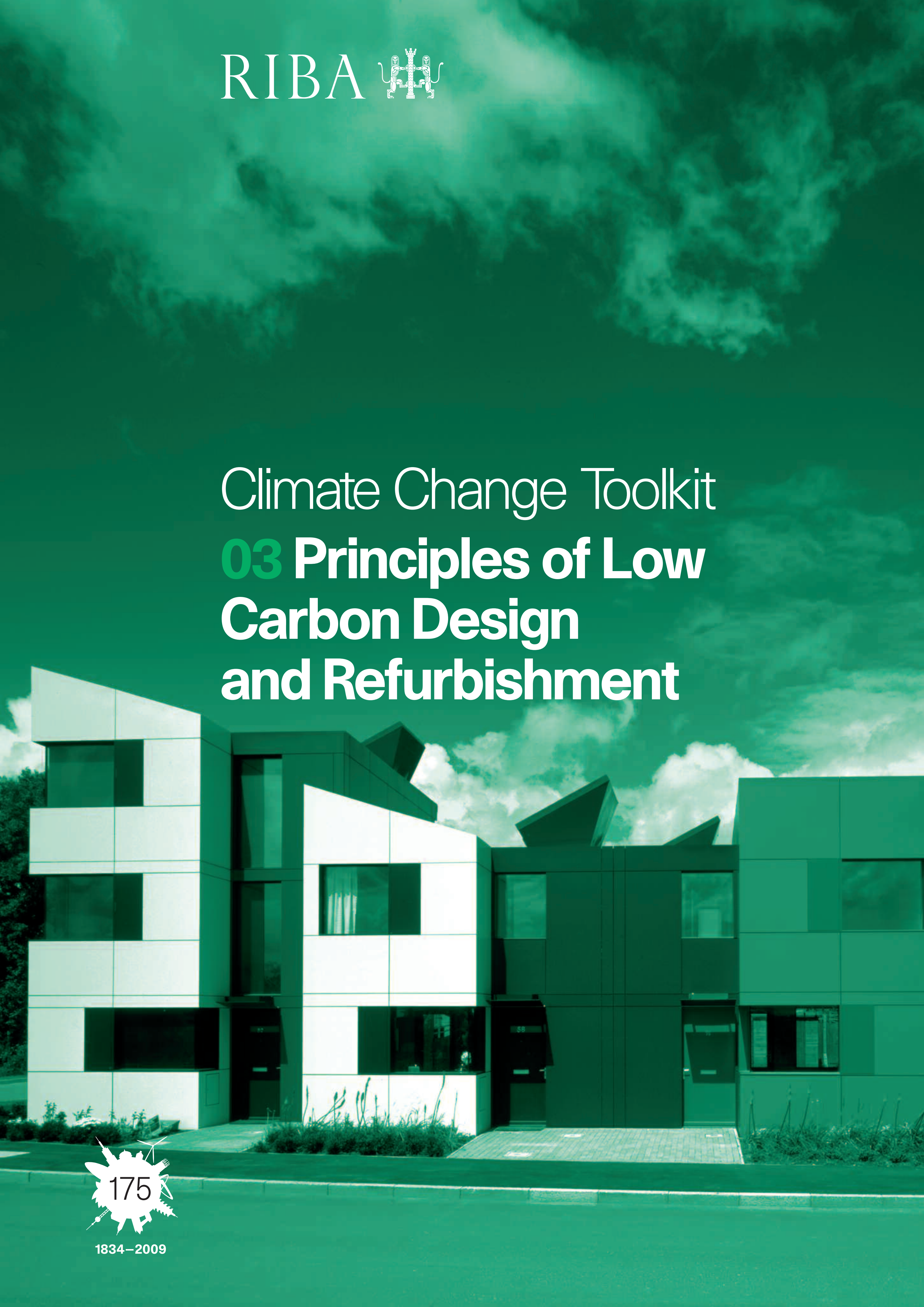
RIBA

Climate Change Toolkit

03 Principles of Low Carbon Design and Refurbishment



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Cover image Oxley Woods. Rogers Stirk Harbour + Partners design for the Oxley Woods houses utilises a unique 'EcoHat'. Essentially a chimney, the EcoHat is situated on top of the services spine and reuses hot air circulating through the stack – complemented by solar energy – to optimise energy consumption and provide passive solar water heating.

Photo Katsuhisa Kida/Rogers Stirk Harbour + Partners

About this Document

This is the third of eight components of Climate Change Tools, a package of guidance developed by the RIBA to encourage architects to engage with the issue of climate change and to deliver low carbon new buildings and low carbon refurbishment of existing buildings.

This document provides a guide to the Principles of Low Carbon Design and Refurbishment. The complete toolkit consists of:

01 *Climate Change Briefing*

02 *Carbon Literacy Briefing*

03 *Principles of Low Carbon Design and Refurbishment*

04 *Low Carbon Standards and Assessment Methods*

05 *Low Carbon Design Tools*

06 *Skills for Low Carbon Buildings*

07 *Designing for Flood Risk*

08 *Whole Life Assessment for Low Carbon Design*

Each guide summarises its subject and provides links to other sources of more detailed information.

You can explore all of the RIBA Climate Change Tools at www.architecture.com/climatechange

Introduction

Climate change brought about by man-made emissions of greenhouse gases has been identified as the greatest challenge facing human society at the beginning of the twenty-first century.

Carbon dioxide is one of the major greenhouse gases. In 2003, carbon dioxide emissions associated with energy use in the UK were approximately 560 million tonnes. Almost half of this was associated with energy use in buildings.

Action to address climate change falls into two categories: mitigation policies are designed to reduce greenhouse gas emissions to slow down or stop climate change; adaptation policies are designed to adjust society to cope with climate changes that are already happening or are likely consequences of current GHG emissions. *The Climate Change Briefing* that forms part of the RIBA Climate Change Tools explains the mechanisms of climate change, summarises UK emissions and explains the challenge that climate change presents to our society.

Architects face a new challenge at the beginning of the twenty-first century: how to ensure that the new buildings they design and the existing buildings they refurbish emit dramatically less carbon dioxide than has been common practice in recent decades. low carbon buildings are designed to produce significantly lower carbon dioxide emissions than others, helping to mitigate climate change.

Some robust principles of energy efficient, low carbon design have been established over the past thirty years. Many experimental and exemplar low carbon buildings have been created, monitored and extensively evaluated.

This guide deals first with domestic buildings, then with non-domestic buildings. It summarises the key principles that should be adhered to in order to achieve a low carbon design[1], and provides links to sources of more detailed information. Finally, the guide presents some information about new and renewable energy systems that is common to both sectors.

Dwellings, as a class of buildings, are more homogenous than non-domestic buildings, which fall into many more types. Therefore this guide is inevitably more specific about dwellings than about non-domestic buildings.

Principles of Low Carbon Design

There are some well-established, over-arching principles of low carbon design:

1 Understand energy use in the building type

It's vital that architects understand the breakdown of energy use for the building type, at least by fuel type and ideally by end-use, i.e. heating, cooling, lighting etc. This enables the designer to focus on the most important issues and identify how to minimise carbon dioxide emissions. The pattern of energy use is important, not just annual totals, particularly when renewable energy technologies are being considered.

2 Use the form and fabric of the building to minimise energy demand

Architects should use their skills to design the form and fabric of the building to do as much of the work of environmental modification as possible, thus minimising the demand on services such as heating and lighting. low carbon buildings should exploit useful solar and internal heat gains (from people, equipment, etc.) to satisfy as much of the heat demand as possible, but exclude unwanted solar gains when they may lead to overheating[2].

3 Focus on insulation and air tightness

low carbon designs seek to reduce unwanted heat losses and gains by adopting appropriate standards of insulation and air tightness. To identify appropriate standards it is necessary to understand the heating and/or cooling balance of the building. Generally the design of a dwelling will focus on keeping heat in and making use of heat gains, while the design of an office will focus on keeping the building cool, especially in summer.

4 Use high efficiency building services with low carbon fuels

The architect should satisfy the remaining energy demand with building services that are as efficient as possible, and that use fuels with low carbon dioxide emissions factors. Emissions factors are explained in more detail in the *Carbon Literacy Briefing* that forms part of the RIBA Climate Change Tools. Architects should also ensure that heating controls are as responsive as possible, to facilitate use of solar and internal heat gains without over-heating the building.

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[1] Note that the generic principles presented here should be applied as appropriate to the context, and may need to be adapted for some building types.

[2] Note that the more a building is insulated, the shorter its heating season. Consequently there are less useful solar gains (because there is less sun in winter). Note also that as insulation standards and summer temperatures increase, avoiding overheating has become a significant problem in buildings of all types, including dwellings.

5 Manage energy within the building

low carbon design is not enough; low carbon operation is also needed. Architects can enable efficient operation of the building by ensuring that appropriate metering and energy management systems are in place, and that the occupants are well-informed about how the building and its services are intended to be used.

6 Use renewable energy systems

low carbon buildings use renewable energy systems to reduce the carbon dioxide emissions associated with the provision of heat and power within the building.

Domestic Buildings

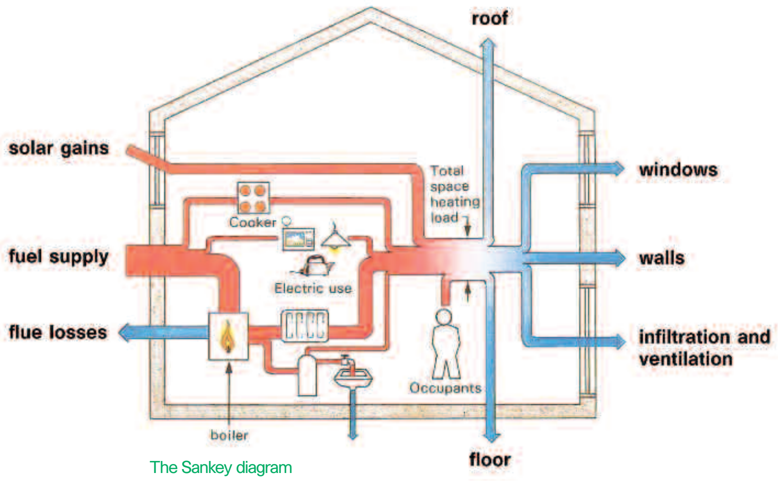
The Sankey diagram

A very useful way of assessing energy flows in a dwelling is to look at the Sankey diagram (below). This shows the heat flows that occur when a dwelling is heated and it is cold outside. The sizes of the arrows provide an approximate indication of the relative sizes of the heat flows.

On the right of the diagram are the heat losses: through the roof, walls, windows and floors, through infiltration and ventilation and through thermal bridges. These heat losses make up the total space heating load.

Most people might assume that the heating system provides all the energy to meet this space heating load but the diagram shows that heat is also provided from:

- Solar gains
- Heat gains from cooking, lights and appliances
- Heat gains from people
- Gains from occupants' use of hot water.



The Sankey diagram

In a modern, well insulated dwelling, the hot water will be a bigger heat load than the space heating, and the internal and solar heat gains will provide much more of the heat required than the heating system itself.

Total space heating load

The total space heating load is made up from:

- **Fabric losses** – through walls, floors, roofs, windows, rooflights and doors
- **Thermal bridging losses** – at junctions and around openings
- **Ventilation losses** – via infiltration and ventilation.

The pie chart below shows the relationship between these three heat loss routes for a house insulated to modern standards but with poor air-tightness and large thermal bridges. It can be seen that the losses via these two routes together can be as much as the fabric losses.

The following sections explore each type of heat loss in more detail.

Fabric heat losses

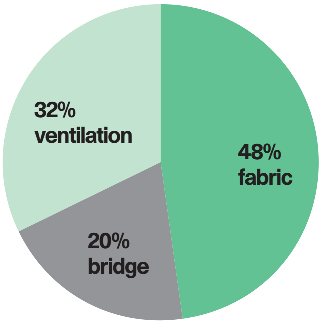
Heat losses through the building fabric – the exposed walls and floors, roofs and openings (windows, roof windows and doors) – are usually the largest heat loss in a dwelling, typically accounting for over 50% of the total space heating load.

These fabric losses are dependent on three factors:

- The area of the element
- The amount of insulation (usually expressed as a thermal transmittance or 'U value')
- The temperature difference between inside and outside.

The heat flow through any element is expressed by the simple formula:

Heat flow = Area x U value x Temperature difference



Heat loss W/C

Thermal bridges

Repeating thermal bridges

When calculating fabric U-values, the effect of repeating thermal bridges is taken into account in the calculations. These repeating thermal bridges include:

- Timber studs in insulated timber frame walls
- Joists in insulated ceilings
- Rafters in insulated pitched roofs
- Mortar joints in lightweight blockwork
- Steel wall ties

The BRE publication *Conventions for U Value Calculations*[3] sets out procedures for calculating thermal transmittances correctly, taking into account heat transfers at surfaces, through fabric layers (insulated and uninsulated), through air spaces, via repeating thermal bridges, through metal fixings (e.g. wall ties), via gaps in insulation layers and via building features such as loft hatches and recessed light fittings.

Non-repeating thermal bridges

Thermal bridges also occur at the junctions between elements where there is a concentration of heat flow because of the geometry of the junction. These are called non-repeating thermal bridges and depend on the design of the construction detail and in particular on the continuity of insulation – how well the insulation layer in one element connects with the insulation layer in the adjacent element.

The diagram below left illustrates a non-repeating thermal bridge at the junction of a ground floor and an external wall.

Non-repeating thermal bridges become a significant source of heat loss in well insulated buildings. Poor detailing at these junctions can add 25% to the heat loss of a well insulated dwelling.

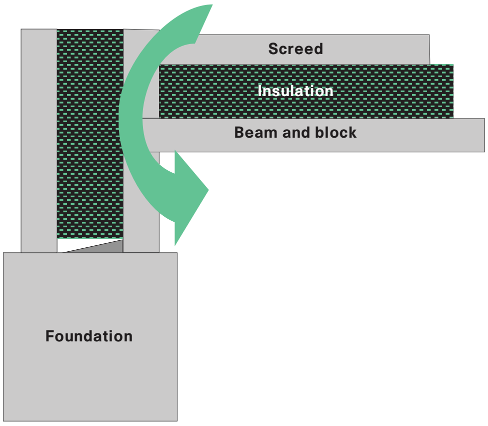
Reducing thermal bridges is therefore a key task when designing a low carbon dwelling: care must be taken to link the insulation in each element to the insulation in adjacent elements, to form a continuous envelope. This is often easier to achieve when the insulation is on the inside or outside of the construction, rather than in the middle of the construction. It should also be noted that small changes in construction details can deliver significant improvements in thermal performance (i.e. lower linear thermal conductivities, or ‘Ψ values’[4].

Random thermal bridges

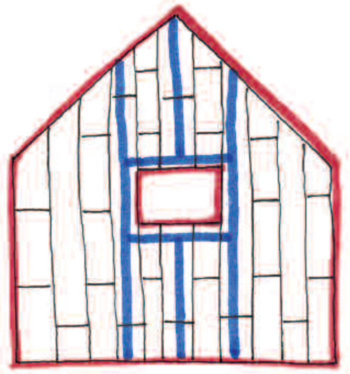
There are also random thermal bridges that occur, for example, when extra studs or timber members are inserted into a construction to support a purlin or ridge beam, or to carry structural loads around an opening.

The diagram below illustrates repeating thermal bridges (black), non-repeating thermal bridges (red) and random thermal bridges (blue) in the gable wall of a timber-framed building.

The image below shows random thermal bridges in (incomplete) timber-framed walls[5].



Non-repeating thermal bridge



Random thermal bridges in timber-framed walls

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[3] Anderson B (2002) *Conventions for U Value Calculations*, publication BR 443, BRE Ltd, Watford

[4] See for example the Accredited Construction Details and the Energy Saving Trust's *Enhanced Construction Details* at www.planningportal.gov.uk

[5] Pictures courtesy of Malcolm Bell, Leeds Metropolitan University

The thermal conductivities of various building materials

Material	Conductivity (W/mK)	Relative to insulation
Insulation (high performance)	0.023	1.0
Insulation (air based)	0.040	1.7
Wood	0.130	5.7
Concrete block (medium density)	0.500	20
Glass	1.050	40
Steel	50.00	2,000

Factors used in calculating heat losses

Several numerical factors are used in calculating the heat losses from buildings.

Thermal conductivity (λ value)

The thermal conductivity of a building material (in W/mK) is a measure of its ability to conduct heat. It represents the amount of heat (in W) that will be conducted through the material per unit of thickness (in m) per unit of temperature difference across it (in degrees K). Thermal conductivities vary from 0.023 W/mK for high-performance insulation to 50 W/mK (2,000 times greater) for steel, as shown in the table left.

Thermal transmittance (U value)

The thermal transmittance of a construction element (in W/m^{2}K) is a measure of its ability to transmit heat. It represents the amount of heat (in W) that will be transmitted through the construction per unit of area (in m^2) and per unit of temperature difference across it (in degrees K). The U values of building elements are multiplied by their areas to calculate the heat losses through them.

Calculation of the correct thermal transmittance, or U value, is at the heart of the design of well insulated building fabric. To ensure that energy standards are met and that heat losses are not significantly above predictions, accurate U values must be calculated.

Ten years ago the only heat loss considered when calculating a U-value was heat transfer through insulated elements. Today U-values must be calculated in accordance with a series of European standards. These are summarised in the BRE publication *Conventions for U Value Calculations*.

Taking account of these heat transfers can make a significant difference to the U value: for a wall with a U value of around 0.3 W/m^{2}K, ignoring these heat transfers can result in an error of 15%.

There are many easy-to-use U value calculators on the market which have these refinements built in, and thus provide accurate calculations consistent with the European standards as required by energy rating assessments. Architects need to be aware of the calculation method, so that checks can be made on U value calculations supplied by third parties.

Currently, the experience of domestic energy rating assessors is that U value calculations supplied by architects, consulting engineers and builders are often wrong, usually because the effects of repeating thermal bridges, fixings and gaps in insulation layers have been ignored. Now that buildings are highly insulated, these issues, which could once be regarded as relatively minor, have much greater significance.

Linear thermal transmittances (Ψ value)

The linear thermal transmittance (in W/mK) of a construction detail is a measure of its transmission of heat by thermal bridging. It represents the amount of heat (in W) that will be transmitted through the detail, per unit of its length (in m) and per unit of temperature difference across it (in degrees K). The Ψ values of construction details are multiplied by their lengths to calculate the thermal bridging losses through them.

The UK Accredited Construction Details (ACDs) and the Energy Saving Trust's Enhanced Construction Details (ECDs) all have known Ψ values. The Ψ values of other details may be calculated using special software, according to a procedure set out in BRE Information Paper IP 1/06. Essentially, the Ψ values of construction details supplement the U vales of building elements in calculations of fabric heat losses.

Thermal bridging transmittance (y value)

The thermal bridging transmittance of a building envelope is a measure of the overall transmission of heat through the construction details by thermal bridging. It represents the amount of heat (in W) that is transmitted through all the construction details per unit area of the entire building envelope (in m^2) per unit temperature difference between inside and outside (in degrees K).

When Ψ values are unknown, a whole-building y value may be used instead to represent the overall heat loss due to thermal bridging. U values and y values have the same units, and the overall thermal transmittance of the building envelope is the sum of the average U value and the y value.

Default y values may be used in SAP energy rating calculations to represent dwellings in which only Accredited Construction Details are used (y = 0.08 W/m^{2}K) or where the thermal characteristics of the construction details are unknown (y = 0.15 W/m^{2}K)

Infiltration and ventilation heat losses

Infiltration is the uncontrolled, unintentional wind- or stack-driven leakage of cold external air into the building through cracks and imperfections in the fabric.

Infiltration is of course accompanied by exfiltration – the loss of warm air, usually from the opposite (downwind) side of the building.

Ventilation is the deliberate introduction of fresh air to combat odours and contaminants – particularly water vapour.

If infiltration is not controlled it can be a significant source of heat loss accounting for as much as 30% of the total space heating load in a well insulated dwelling. As importantly, if the exfiltration of moisture laden warm air passes through the fabric, interstitial condensation will take place on any cold surfaces. This can be a problem particularly in timber constructions.

Dwellings in the UK are notoriously leaky. While much has been done to improve insulation levels, little has been done to reduce heat losses due to infiltration. Unless air leakage is controlled, it can form a large proportion of the heat loss in a well insulated house. The mantra must be: 'build tight, ventilate right'. Ventilation should be provided where and when it is needed – not as a huge continuous background infiltration rate.

To reduce infiltration requires a strategic approach to the design and construction of an airtight envelope. A target for the air permeability of the envelope should be part of this strategy. An air pressure test can then be carried out after construction, to confirm that the design intent has been achieved[6].

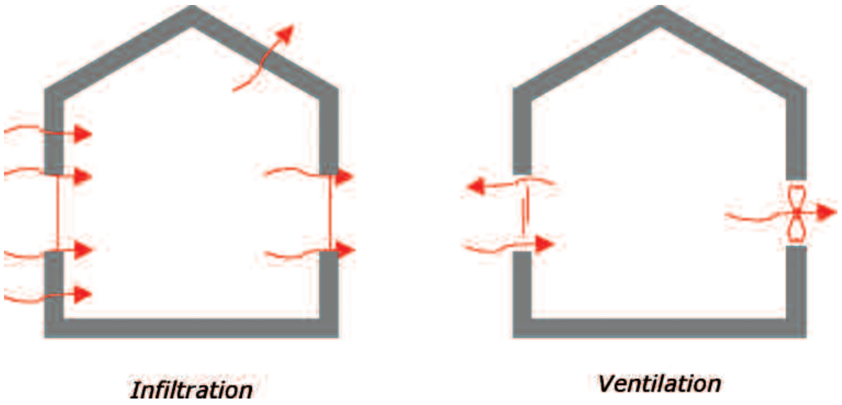
Commonly used air permeability standards

The Approved Document to Part L1A of the Building Regulations (2006) calls for a maximum air permeability of 10 m^3/hm^2 @ 50 Pa.

CIBSE Technical Memorandum 23 *Testing Buildings for Air Leakage* recommends a best practice air permeability of 8 m^3/hm^2 @ 50 Pa for naturally ventilated dwellings, and 4 m^3/hm^2 @ 50 Pa for mechanically ventilated dwellings.

ATTMA Technical Standard 1 *Measuring the Air Permeability of Building Envelopes* recommends a best practice standard of 3 m^3/hm^2 @ 50 Pa for all dwellings, whether naturally or mechanically ventilated.

Some of the best dwellings in the UK have air permeability less than 3 m^3/hm^2 @ 50 Pa, but even this is poor compared with the PassivHaus standard of less than 0.6 m^3/hm^2 @ 50 Pa.



Infiltration and ventilation heat losses

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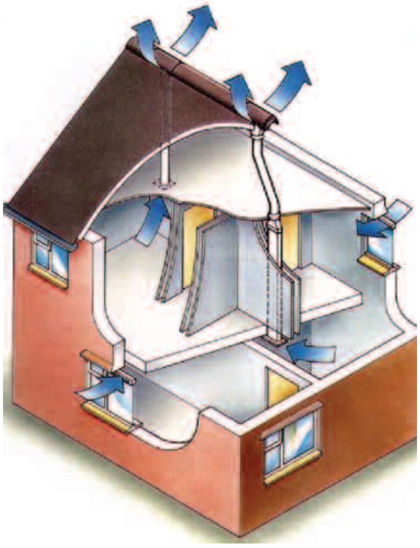
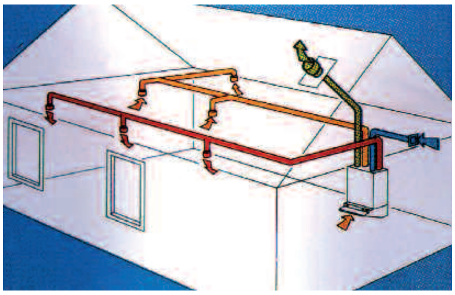
[6] CIBSE (2002) *Testing Buildings for Air Leakage*, Technical Memorandum 23, Chartered Institute of Building Services Engineers, London

Typical domestic pressure testing equipment



Passive stack ventilation



Mechanical ventilation

Excessive air leakage is often blamed on poor workmanship on site, but the design strategy is at the heart of achieving good standards of air-tightness. The most important aspect of this is being able to identify a continuous air barrier that will prevent infiltration. Air barriers in the walls should connect to those in the roofs and floors, and there should be a clear strategy for sealing the air barrier around openings.

Designers should be clear about how air-tightness is to be achieved, and think in three dimensions about the continuity of the air barrier between elements and between various components for which different suppliers, sub-contractors and installers may be responsible.

Air barriers do not necessarily have to be sheet materials like polythene. Other techniques for achieving airtight constructions include wet plaster finishes on masonry walls and sealing boards to studs and noggins in timber frame construction.

An important way of ensuring that the design intent is achieved on site is to specify an appropriate air permeability target, and that compliance with the target must be confirmed on site by means of an air leakage test[7].

This involves pressurising the dwelling using a special fan. The air permeability is calculated by dividing the airflow (m^3/h) through the fan at a pressure difference of 50 Pa by the internal surface area of the dwelling (m^2). Typical domestic pressure testing equipment is shown in the top left image.

Ventilation losses occur when occupants open windows and when they use fans or ventilation systems. Much can be done to control ventilation losses by using a system that supplies ventilation only where and when it is needed.

In air-tight homes, infiltration cannot be relied on to supply ventilation air. Ventilation is required to maintain good air quality and remove moisture and other contaminants, so an appropriate ventilation system must be specified.

The provision of this ventilation system, with its associated ductwork can have significant implications for the design and layout of the dwelling. Routing ductwork can be a major problem unless it is integrated into the design at an early stage.

There are several options for ventilation systems[8]:

- Passive stack ventilation
- Whole-house mechanical extract ventilation
- Whole-house mechanical ventilation with heat recovery.

Passive stack ventilation (PSV) relies on the stack effect to extract air from kitchens and bathrooms. Air to the dry rooms should be supplied by humidity controlled air inlets (e.g. ‘trickle ventilators’) in the walls or windows (see the illustration below left). There is some doubt over the use of PSV in very airtight dwellings and it is not recommended at air permeabilities less than 3 m^3/hm^2.

The advantage of PSV is that it does not rely on fans to move the air around the house. However, the use of fans does give a more constant and reliable air supply.

Mechanical extract ventilation (MEV) can provide a constant low air change rate with the ability to boost the extract rate during cooking or bathing. The position of air inlets should be carefully planned so that they do not cause draughts. To ensure that the fan does not use excessive amounts of electricity, fan power should be limited to 0.3 W/(l/s) (0.08 W/(m^3/h)).

PSV and MEV systems throw away the warm moist air and replace it with cold outside air. This results in significant heat losses in well-insulated homes.

Mechanical ventilation with heat recovery (MVHR) systems will recover some of the heat in the extract air and pass the heat to warm the supply air (see the diagram left). Most MVHR systems use two electric fans – one supply and one extract fan. If the fan power is not carefully controlled the carbon dioxide emissions associated with the use of electricity for the fans may outweigh the reduction in emissions associated with the heat recovered from the extract air. It is important that heat recovery efficiencies are over 80% and that fan power is below 1 W/(l/s) (0.278 W/(m^3/h)).

In a house with a total heat loss of less than 10 W/m^2 (of floorspace) it is possible to introduce the small amount of heat required via the ventilation system. This is common practice in dwellings built to the PassivHaus standard.

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[7] Sample pressure testing of new dwellings, and individual testing of most other buildings, is required by Part L of the Building Regulations

[8] The use of positive input ventilation (PIV) should not be considered. It relies on air escaping from the house via gaps and cracks in the construction. Such cracks and gaps should not be present in a low carbon home, but if they were then passing warm moist air through the construction where it will condense would not be wise!

Construction details – points for architects to watch

Achieving low carbon homes requires a fundamental rethink of many traditional construction details. They need to be re-examined in terms of their levels of insulation, thermal bridging and air-tightness. Many common details are poorly insulated, contain repeating, non-repeating and random thermal bridges and are poor at reducing infiltration. Many of these problems can be overcome if certain 'dos' and 'don'ts' are observed.

Do

- Allow for much thicker insulation than has been common in the past
- Remember that wide fully filled cavities can be used in areas of severe exposure (see *Thermal Insulation: Avoiding Risks*[9] and BS 8104)
- Make sure that the insulation layer in one element connects with the insulation layer in the adjacent one
- Make sure there is a clearly defined air barrier in each element that connects to the air barrier in the adjacent element
- Make sure that the air barrier can be installed on site – e.g. plaster in intermediate floor zones or behind stairs
- Ensure that there is an air barrier on each side of a layer of insulation to prevent air circulation from the cold side to the warm side
- Remember that wood is not a good insulator; therefore reduce the effect of repeating thermal bridges in timber constructions by the use of counter battens, additional insulation layers, spaced studs, or I studs and I beams
- Consider insulation at rafter level to avoid problems with cold roof spaces
- Keep all the services within the insulated envelope, create services zones on the warm side of the insulation and air barrier and detail any penetrations to eliminate air leakage

Don't

- Use quilt insulation in lofts with trussed rafters – it is impossible to lay the insulation properly across the ceiling joists; use a blown insulation
- Specify partial cavity insulation unless the insulation is fixed to the inner leaf with adhesive and all joints between boards are taped on the cavity side
- Build timber joists into masonry walls; use joist hangers instead
- Use plasterboard on dabs without sealing the wall behind; consider the use of gypsum parging and air barriers or tapes around openings

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[9] *Thermal Insulation: Avoiding Risks* Building Research Establishment, Watford, 1994

Heat gains

It might be thought that the heating system is used to supply the heat needed to satisfy the total heating load. But the Sankey diagram shows that much of the load is met from other heat gains. Heat gains come from:

- Solar gains through south facing windows
- Cooking and the use of lights and appliances
- Hot water storage and use in the house
- The occupants themselves.

Careful design can optimise the benefit of solar gains without causing summer overheating. Generally other gains, using expensive electricity, should be reduced.

There is much the designer can do to reduce these gains. For instance, good daylighting and low energy lights will reduce electricity used for lighting, low energy appliances can be installed and hot water cylinders can be superinsulated and pipework insulated.

Heating systems

Even very well insulated, air-tight dwellings require some form of heating system. It will be needed on exceptionally cold days, and to bring the dwelling up to temperature after and during periods with low occupation.

To be effective a heating system should be:

- **Efficient – e.g. a seasonal (SEDBUK) efficiency of over 90%**
- **Responsive – responding rapidly to heat loads and temperatures**
- **Well controlled – user-friendly time and temperature control.**

In dwellings with heat losses over 10 W/m^2 it is likely that a central heating system will be the most suitable form of heating. In many dwellings this will be a gas-fired system. An efficient well controlled system will result from following the guidance in the *Domestic Heating Compliance Guide*[10].

Whilst fossil fuels are presently dominant, there are already some technologies available that have the potential to significantly reduce carbon dioxide emissions. These include biofuels, heat pumps and combined heat and power.

Biofuels

Biofuels produced from plants have the ability to be carbon neutral – the carbon dioxide absorbed during growth is released during burning. To be carbon neutral, the fuels must come from sources which are continually replenished and energy should not be used to convert the fuel into a useable form. In practice, most 'carbon neutral' fuels have small carbon dioxide emissions associated with their conversion and transportation.

Liquid fuels from sources such as sugar cane or rape seed are beginning to be used in transport but at present there are no bio-oil boilers suitable for the domestic market.

Wood fuel, on the other hand, has always had a role in the domestic heating market. Logs, wood chips (shown below) and wood pellets are all being used to heat domestic premises. Logs can be used in boilers or wood burning stoves. Wood chips have a role in centralised boiler schemes where fuel storage and handling plant can be incorporated. Wood pellets can be used in stoves or boilers. Pellets give better controllability but are expensive.

It is likely that wood fuel will continue to make a small contribution to domestic heating but the area of land required to grow biomass to make a significant contribution is more than the area available in the UK and other uses such as transport will increasingly compete for this limited resource.

Wood chip fuel

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[10] Office of the Deputy Prime Minister [now Communities and Local Government] (2006) *Domestic Heating Compliance Guide*, second-tier Building Regulations, Part L guidance document, NBS, London

Heat pumps

Heat pumps are often portrayed as a renewable energy source. In fact they are simply a relatively efficient way of using electricity to provide heating.

Heat pumps use a refrigeration cycle to raise the temperature of heat from a source (e.g. the outside air or ground). Ground source heat pumps (GSHPs – see the diagram below) have advantages because the source is at a stable temperature. The efficiency of a GSHP is typically 300% (referred to as a coefficient of performance (CoP) of 3 – three units of heat are extracted from the ground for every one unit of electricity used by the heat pump).

The efficiency is higher if the temperature supplied by the heat pump is near that of the source. So heat pumps are often used with under-floor heating to provide a large area of heat emitter at a relatively low temperature (compared with radiators emitting heat from a boiler).

The carbon dioxide emissions from an efficient electric heat pump incorporated into a well-designed heating system can match those of the best performing gas-fired systems. Carbon dioxide emissions are potentially very low, but only if the electricity to run the heat pump is produced from renewable sources.

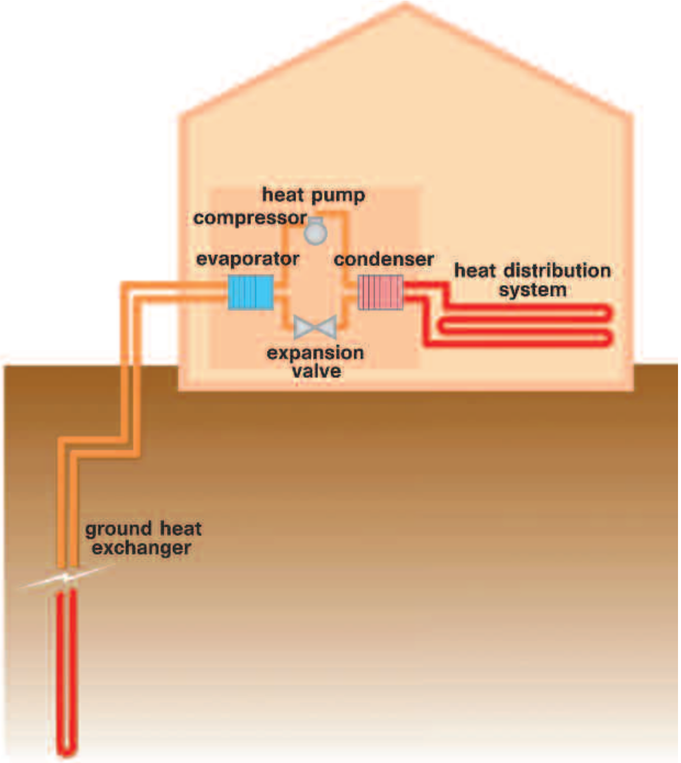
Heat pumps can be used to provide cooling, and generally have a higher CoP in cooling mode than in heating mode, but they should not be thought of as 'free' or 'low carbon' cooling – in the UK cooling dwellings is usually unnecessary, and using electricity for this purpose, even in a heat pump, should always be avoided.

Combined heat and power (CHP)

CHP can be used at the scale of a district, estate or large block to provide communal heating and hot water supply combined with local electricity generation. Typically, a gas-fired engine is used to drive an electricity generator and the waste heat from the engine is used for space- and water-heating.

Although providing space- and water-heating in this way is slightly less efficient than using a gas-fired boiler, significant overall carbon dioxide emissions savings can result from the much improved efficiency of local electricity generation compared with that of mains electricity.

Sometimes CHP systems are sized to match thermal loads, resulting in excess electricity generation and the need to sell the surplus to an electricity company. Alternatively, if CHP systems are sized to match electricity loads, supplementary heating from boiler plant may be required. Good balancing of thermal and



Ground source heat pump
(source: Energy Saving Trust)

electrical loads (which can be achieved in mixed-use developments) improves the efficiency of the CHP system.

CHP that uses biomass as its fuel offers the prospect of zero-carbon heating, hot water and electricity for developments with an appropriate heat density and mix of heat and power demands. However, biofuel CHP usually involves gasification of biomass, before it can be burned in the CHP plant; this is an emerging technology that is not yet mature, robust or reliable – but it is one to watch, particularly for high-density urban applications.

Micro CHP (i.e. domestic-scale combined heat and power) improves the overall efficiency of a household heating system by using it to generate electricity as well as heat in a compact unit[11]. A gas-fired engine is used to drive a generator, and the waste heat from the engine is used for space heating and hot water. Units currently on the market typically use a Stirling engine to produce about 1 kW of electricity while producing between 6 kW and 8 kW of heat.

Micro CHP is relatively expensive to install, compared to boiler-based central heating. To justify the investment, it is important that the CHP unit has sufficient thermal load to ensure that it runs for a substantial part of the heating season. In low carbon homes this will not usually be the case – the heating is only required for short periods. Thus the best market for micro CHP is in hard-to-insulate existing homes or in conjunction with communal heating for blocks of flats or other high density developments.

Water heating

In well insulated, air-tight, low carbon homes, the main use of the heating system is often to provide hot water, with space-heating as a by-product. This means that carbon dioxide emissions associated with energy use for hot water supply will usually be more than those associated with energy use for space heating. This is the opposite of what we are used to.

Much can be done to reduce hot water fuel use by:

- Specifying low water use fittings (to reduce demand)
- Specifying an efficient heating appliance
- Strategic positioning of any hot water cylinder
- Specifying an efficient, well insulated cylinder
- Sizing and insulating distribution pipework properly.

Combination boilers

Combination boilers, or 'combis', have between 60% and 70% of the gas boiler market at present. They provide 'instant' hot water, without a pre-heated hot water storage cylinder, as well as supplying heat to radiators. Combi boilers have the advantage of providing mains pressure hot water in a very efficient manner, with no tanks or pipework in the loft space. Overall water heating efficiencies can be around 10% higher than for cylinder based systems.

Care is needed with combi boilers incorporating 'keep hot facilities' that keep the domestic hot water heat exchanger hot, because efficiency gains can be negated by the fuel use and/or storage losses associated with the 'keep hot' system.

A major drawback with combi boilers is that many are unable to accept pre-heated water from a solar water heating system. By contrast, hot water systems with indirect storage cylinders can include 'twin coil' cylinders with a solar heat exchange coil as well as one from the boiler.

Solar hot water systems

A typical solar hot water system will use a solar collector to heat domestic hot water in a dual coil cylinder. In the UK, solar water heating will usually reduce the annual fuel demand for water heating by approximately 50%, and meet almost 100% of the hot water demand during the summer months.

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[11] Note however that (unlike large-scale CHP) micro-CHP is an immature technology that is still under development: robust, reliable, mass-market products are not yet available

Lights and appliances

In modern homes, carbon dioxide emissions associated with energy use for lights and appliances will account for around half of all emissions.

It may be thought that the provision of low energy appliances is the occupants' responsibility, but there is a lot the designer can do to reduce emissions from this source. By careful selection of efficient lights and appliances, the carbon dioxide emissions associated with this energy end-use can be halved.

The trend towards providing new homes with built-in appliances offers an excellent, simple opportunity to reduce carbon dioxide emissions. A recent study found that most developers were installing poor quality, inefficient appliances in new homes. Changing to 'A' rated appliances was estimated to have the potential to save 2,800 tonnes of carbon dioxide per year.

Energy efficient lamps such as compact fluorescents and fluorescent tubes will use 80% less energy than the equivalent tungsten lamps[12]. Since the provision of some low energy lights became a requirement of the Building Regulations, the range of low energy domestic light fittings has greatly expanded. Conventional tungsten filament lamps are being phased out across the EU – some sizes of lamp have already become unavailable, and the others will follow over the next few years. At the same time, very low energy LED (light emitting diode) lighting is becoming available.

There really is no excuse for not designing and installing energy efficient lighting in all rooms. The Energy Saving Trust's *Low Energy Domestic Lighting*[13] is a useful source of further information.

Summer overheating

Poorly insulated, draughty houses seldom suffer from overheating in summer. However, now that new and existing dwellings are very much better insulated, small heat gains can cause summer overheating. Heat loss through the building fabric is dependent on the temperature difference between inside and outside, so when the internal and external temperatures are similar (in summer) there is little or no fabric heat loss, so solar and internal heat gains tend to be retained in the dwelling.

Complaints of overheating in new homes have led to the inclusion of a requirement in the Building Regulations for an overheating check to be carried out via SAP 2005. The associated design guidance illustrates three key strategies for tackling summer overheating. These are:

- Reducing heat gains – by selecting energy efficient appliances and reducing summer solar gains through glazing (particularly on the south west or west elevations)
- Increasing heat losses – by secure night time ventilation
- Increasing thermal mass – allowing heat gains to be stored in the fabric before being removed by night time ventilation.

The most important of these is providing secure night time ventilation. It is a challenge for the designer to provide large ventilation openings that can be left open at night without compromising security, particularly in single-aspect ground-floor flats. Proprietary fixed ventilators, shutters and window grilles can be useful for providing secure ventilation openings. A guide from the Energy Saving Trust *Reducing Overheating*[14] provides further information.

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[12] Note that energy efficient lamps are defined as those that deliver at least 40 lamp lumens per circuit Watt; this definition includes fluorescent tubes and compact fluorescent lamps, and most LED lighting, but not halogen lamps or low voltage install-ations (which use as much energy as tungsten lamps)

[13] *Low Energy Domestic Lighting – A Summary Guide* General Information Leaflet 20, Energy Efficiency Best Practice in Housing, Energy Saving Trust, London, available via www.est.org.uk

Importance of a strategic approach

Irrespective of the type of non-domestic building that is being designed, it is important that a strategy for achieving a low carbon building is a high priority from the initial stages of design development.

As the design develops, choices are made about the building form and fabric, and about its servicing systems, and consequently the number of energy savings options is progressively reduced. It is much more difficult and expensive to 'bolt on' energy efficiency and low carbon features to a well developed design than to integrate them into the design strategy from the start.

Non-Domestic Buildings

Introduction

The six principles of low carbon design set out in the introduction to this guide apply equally to domestic and non-domestic buildings. They are:

1. Understand energy use in the building type
2. Use the form and fabric of the building to minimise demand
3. Focus on insulation and air tightness
4. Use high efficiency building services with low carbon fuels
5. Manage energy use within the building
6. Use renewable energy systems.

Most of the guidance provided in the previous section, with respect to dwellings, is equally applicable to non-domestic buildings, especially where their scale and construction are similar to those of domestic buildings. In particular, the same considerations apply to the building fabric – where providing a very good standard of insulation and air-tightness and minimising thermal bridging are all important – and to the services, where efficiency and responsiveness are essential.

There are, however, two differences between dwellings and non-domestic buildings that significantly affect their energy use and carbon dioxide emissions, and thus demand a different approach to low carbon design. These differences are:

- The activities accommodated, which are much more varied than in dwellings
- The built form – non-domestic buildings are often much larger than dwellings.

This part of this guide will therefore focus on these differences, and related issues such as daylighting, internal heat gains and natural ventilation, reviewing their implications for low carbon design and refurbishment.

Extensive and detailed general guidance on this subject, with a focus on non-domestic buildings, appears in two CIBSE publications:

- CIBSE Guide F *Energy Efficiency*[15]
- CIBSE Guide L *Sustainability*[16].

We recommend that this guide should be read in conjunction with both of these documents.

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14 *Reducing Overheating – A Designer's Guide* (CE129), Energy Efficiency Best Practice in Housing, Energy Saving Trust, London, available via www.est.org.uk

15 CIBSE (2004) *Energy Efficiency* Guide F, Chartered Institute of Building Services Engineers, London

16 CIBSE (2007) *Sustainability* Guide L, Chartered Institute of Building Services Engineers, London

Activities

Non-domestic buildings accommodate a huge range of activities, many of which involve relatively high densities of occupation, high lighting levels and high equipment densities, all of which give rise to internal heat gains. For example:

- In **deep-plan offices**, much of the energy demand is in the form of lighting and equipment. Other key demands are from ventilation (often with cooling) to remove the internal heat gains from people, lights and office equipment. Many office buildings are heated for only a few hours in the early morning, even in winter; for the rest of the day the heating demand is swamped by internal heat gains.
- Similar points may be made about **large retail buildings** – department stores, supermarkets and out-of-town retail 'sheds'. These buildings often combine deep plans (making daylighting and natural ventilation difficult to achieve) with very high lighting levels (for display purposes). Supermarkets contain large numbers of refrigerated cabinets and freezers that use electricity and reject heat (often into the space), and retailers of appliances such as computers and televisions often have many such devices operating in shop displays, again using electricity and giving off heat.
- **Schools and colleges** have different occupancy patterns again. The density of occupation may be very high (thirty students and two teachers in a classroom or seminar space), but very intermittent (often they all go to different classrooms, or assemble in a school hall, or even leave the building altogether at break times or for sport). School buildings are increasingly used for community purposes, outside school hours, but such activities often only involve use of a small part of the building, while the rest remains empty. Teaching spaces are traditionally provided with high lighting levels (by either natural or artificial lighting) leading to potentially high solar and/or lighting heat gains. More equipment is also finding its way into schools and colleges, in the form of computer networks, printers, projectors and electronic whiteboards. The main focus of energy efficient school design is usually on ways of achieving good daylighting and natural ventilation in both winter and summer, despite highly variable occupancy, and without recourse to mechanical ventilation or cooling.

The development of a low carbon strategy for a non-domestic building should always start from the activity accommodated and the pattern of occupancy.

Points that should be investigated include:

- **The environmental conditions required (temperature, humidity, air movement, lighting level, etc)**
- **The likely level and pattern of internal heat gains.**

These investigations will help the design team to determine the likely balance of heating and cooling, and the scope for natural lighting and ventilation.

Built form

Prior to the development of electric lighting and of mechanical ventilation and air conditioning systems, buildings were designed to ensure that all occupants were close to sources of daylight and natural ventilation. Floor plans were rarely more than 10 m deep, and relatively high storey heights combined with high windows and rooflights provided daylighting and promoted natural ventilation.

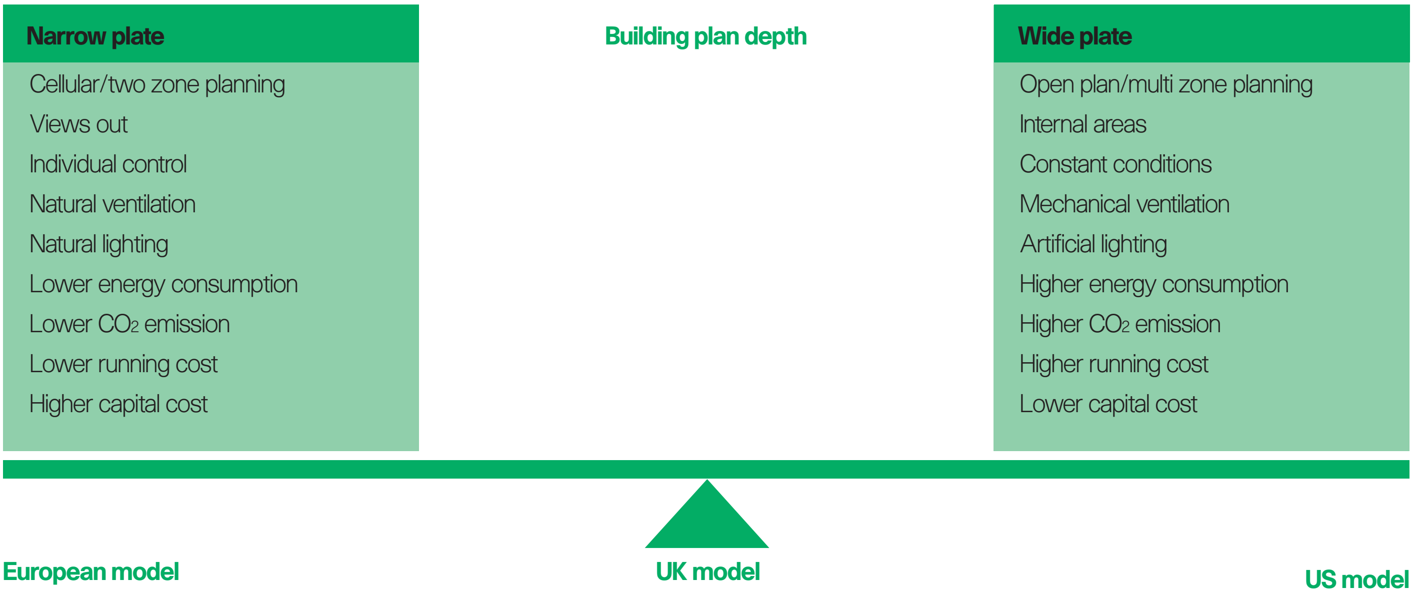
Since the middle of the twentieth century, the designers of large, modern buildings have preferred to provide simpler building envelopes whose form is unrestrained by the need to contribute to the tempering of the internal environment. Such buildings often have many floors, deep plans (typically 15–18 m) and relatively low storey heights. They rely on artificial lighting, mechanical ventilation and air conditioning to provide acceptable internal environments (indeed without the use of energy they would be uninhabitable). Natural light and ventilation are available to occupants of perimeter spaces in a zone up to 7.5 m wide adjacent to the light and ventilation source, depending on the size and location of the windows and the floor-to-ceiling height. A useful rule of thumb is that there will usually be adequate daylight within a distance of 1.5 times the floor to ceiling height from the building perimeter.

However, as they begin to address the challenge of climate change, some architects are realising that this shifting of responsibility for the internal environment (usually to the services engineer) is inappropriate.

The form and fabric of the building should be used to provide an acceptable internal environment, as far as possible, which can then be 'fine-tuned' by the minimum use of appropriate, efficient building services.

This means using built forms that incorporate relatively narrow plans (e.g. building tall and thin, or around courtyards) and increased storey heights to improve daylighting, and that promote natural stack-effect or cross-ventilation.

Environmental considerations related to building depth



Narrow plate	Building plan depth	Wide plate
Cellular/two zone planning		Open plan/multi zone planning
Views out		Internal areas
Individual control		Constant conditions
Natural ventilation		Mechanical ventilation
Natural lighting		Artificial lighting
Lower energy consumption		Higher energy consumption
Lower CO_2 emission		Higher CO_2 emission
Lower running cost		Higher running cost
Higher capital cost		Lower capital cost

Source: BCO

Daylighting

Good daylighting not only reduces the artificial lighting load of a building, it also reduces the heat gains from artificial lighting, and therefore the ventilation or cooling load. It is therefore important to understand the effect of glazing on the energy performance of buildings.

Glazing has a significant impact on the overall energy balance of a building because solar heat gains may be useful during heating periods, but unwanted during cooling periods.

Heat losses through glazing also form a major component of the heating demand so it is important to find the balance between the benefits of solar gains and daylight penetration and the consequences of increased heat loss and of ventilation or cooling demand.

Depending on the building location and orientation, good daylighting is most easily achieved in shallow-plan buildings, where the plan depth is no greater than 15 m. Daylighting can be enhanced using the following principles:

- Optimise the internal layout to facilitate daylight penetration, with work-stations at the perimeter and intermittently occupied spaces located centrally
- Use light surfaces to reflect light into deeper parts of the building. Light shelves can be used to reflect diffuse daylight on to the ceiling, where it will be reflected down to the working area
- Local lighting control will help to reduce energy use and increase occupants' satisfaction. Daylight and occupancy sensors can be used to increase, reduce or switch off electric lighting automatically when it is not required.

In new offices, the glazing ratio (the area of unobstructed glass as a fraction of the total wall area) can vary between 25% and 50%. Glazing ratios above 50% should be avoided because of the increased risk of solar overheating.

For new buildings, glazing ratios are limited by the Building Regulations. When existing buildings are being refurbished it often makes sense to reduce excessive glazing ratios, particularly if the building dates from the 1960s or 1970s and is significantly over-glazed.

Unwanted solar gains can be reduced in summer by shading. East and west facades are more difficult to shade adequately than south-facing facades. North facades are often unconstrained in respect of overheating, but subject to higher heat losses.

The LT Method[17] can be used to guide preliminary design development and establish an appropriate glazing ratio.

Internal heat gains

In non-domestic buildings, the level of internal heat gains is usually higher than in domestic buildings and requires careful control. Heat gains from people, lighting and equipment such as computers and printers can be reduced by:

- Designing the building with adequate space for the intended number of occupants (for example, the British Council for Offices recommends 10–17 m^2 net internal floor area per person for office buildings)
- Removing equipment such as printers and copying machines from occupied spaces into separate spaces with local ventilation, and then specifying high efficiency equipment throughout
- Specifying efficient lighting with local control by daylight- and occupancy-sensors and manual switches, so that lights may be dimmed or switched off when the natural light level is adequate
- Ensuring that installed lighting loads are less than 3 W/m^2 per 100 lux.

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[17] For more information about using the LT Method, see Cambridge Architectural Research Limited *Energy and Environment in Non-Domestic Buildings: A Technical Design Guide*, RIBA, London

Ventilation

Once solar and internal heat gains have been reduced, adequate indoor air quality and thermal comfort can be ensured by providing natural, mechanical or mixed mode ventilation.

The choice of ventilation method is often a critical component of the energy strategy for a low carbon building because it has implications for the building form, the building fabric (e.g. the glazing ratio), the building services and the way that the building should be used.

Natural ventilation

Natural ventilation is most appropriate in buildings that have:

- Narrow floor plans (less than 15m)
- Floor to ceiling heights of approximately 3m
- Good control of solar heat gains (e.g. by shading)
- Well-controlled internal heat gains
- High thermal capacity building fabric (to facilitate night cooling)
- Well-designed and controlled window openings.

There are two main mechanisms for natural ventilation:

- Air pressure differences between opposite sides of the building arising from wind movements around the building. Wind driven ventilation can be very effective, but wind may not blow all the time, especially in high density urban areas.
- Stack driven ventilation – caused by the natural convection of warm air rising within the building. A stack tower, atrium or solar chimney can be used to enhance the stack effect. Warm stale air rises up and leaves the building via high level openings, and cool fresh air enters the building via ventilators at lower levels. The stack effect can be enhanced by wind blowing across the outlets (the venturi effect) and by the height of stack tower.

Mechanical ventilation

Mechanical ventilation is most appropriate to buildings where there is:

- A high risk of summer overheating
- An intermittent ventilation requirement dependent on weather
- External air or noise pollution
- Security issues associated with natural ventilation.

In such cases, ventilation can be wholly or partly provided by mechanical means, and this opens the possibility of using heat recovery to retain some of the heat that would otherwise be lost with the stale air extracted from the building.

Mixed mode ventilation

Mixed mode (or hybrid) ventilation is a combination of natural and mechanical ventilation and is often used in non-domestic buildings.

The variation in ventilation strategy may be either seasonal – where natural ventilation is used in the summer and mechanical ventilation during colder periods – or functional where areas of the building have different ventilation strategies according to the activities they accommodate.

Mixed mode systems can provide comfortable and controllable buildings with relatively low carbon dioxide emissions compared with buildings that are wholly mechanically ventilated.

Cooling

As a general principle, it is best to avoid the use of mechanical cooling and air conditioning altogether. Such systems use large amounts of electricity and significantly increase the carbon dioxide emissions associated with the operation of the building.

However, some types of non-domestic buildings do require cooling, at least in part. For example, cooling may be required because of irreducible internal heat gains (e.g. in a computer centre, call centre or large kitchen) or because natural ventilation is impractical due to external noise or air pollution.

Some innovative and relatively efficient cooling techniques have been developed for application in these circumstances.

Night ventilation

Night ventilation is sometimes used for cooling intermittently occupied office buildings (it doesn't work if the building is continuously occupied). It involves flushing the building with cool external air when it is unoccupied (i.e. at night) in order to cool the interior and chill the fabric of the building. When the building is reoccupied in the morning, the cool building fabric absorbs the heat gains from people, lights and equipment, and contains the internal temperature within acceptable limits until the end of the working day.

This technique only works where there is a significant difference between day-time and night-time temperatures, and when the internally exposed building fabric is of sufficient thermal capacity (e.g. masonry or concrete). It is also important that the night-time ventilation does not compromise the security of the building.

Labyrinths

Labyrinths or 'earth tubes' involve supplying fresh ventilation air to the building via heavy earthenware pipes buried underground or via elaborate underground (basement) structures built from materials of high thermal capacity.

In summer the underground temperature is lower than the air temperature, so the incoming air is cooled as it passes through the earth pipes or labyrinth. Some fan-power is required to move the air through the pipe or labyrinth, but essentially the cooling is 'free'.

In winter the underground temperature is higher than the air temperature, meaning that the ventilation air is slightly pre-warmed and requires less heating before it is supplied to the occupied spaces.

Other building services

Once the demand for heating, lighting and cooling has been minimised by appropriate building form and fabric and a method of ventilation and/or cooling has been adopted, a compatible strategy should be adopted for the other building services.

The architect should work closely with the building services engineer from an early design stage to ensure that the overall services strategy is consistent with the approach to building form and fabric, and vice versa.

Heating, cooling and hot water systems should be designed and specified with their environmental impacts in mind.

If site-wide systems such as district heating, combined heat and power or tri-generation have been identified as being technically and financially viable then significant carbon dioxide emissions savings can be achieved. These systems should be considered alongside renewable energy technologies to ensure that the overall building services provided closely meet the building's energy demands and do not conflict with each other.

Operation and management

A lot of attention is often given to the design and construction of low carbon buildings, but once the buildings are complete and occupied it is important that they are operated efficiently. If the occupants and managers of the building do not understand how to operate it efficiently, then all the design team's efforts are worthless!

Most buildings do not perform as well as their designers intend, and low carbon buildings are no exception. There are many reasons for this and it is recommended that design teams familiarise themselves with the section 'Why buildings fail on energy' at the beginning of Section 15 of CIBSE Guide F *Energy Efficiency in Buildings*.[18]

To ensure energy efficient operation of low carbon buildings, you will need to:

- Provide the occupants and managers with a sound understanding of how the building is intended to work. This information should be provided in the form of a verbal briefing as well as a detailed, building-specific operation and maintenance manual with a clear energy management policy
- Make the occupants and managers aware of the design team's performance targets for the building (the Energy Performance Certificate may assist with this) and how the targets relate to appropriate best practice benchmarks
- Provide the occupants and managers with the means to monitor performance, assess it against the established targets and benchmarks, and identify problems. This involves ensuring that appropriate metering has been installed and, in the case of larger buildings, that the building energy management system has been set up to provide appropriate reports and out-of-range alarms.

The Energy Management Matrix[19] (see opposite) is a useful tool for supporting the operation and management of low carbon buildings.

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[18] **18** See also Bordass W T et al 'Assessing Performance in Use – 2: Technical Performance of the PROBE Buildings' *Building Research Information* 29 (2) 2002.

[19] **19** See CIBSE Guide F *Energy Efficiency in Buildings*, Section 15, or for a more detailed explanation of the matrix see *Organisational Aspects of Energy Management* General Information Report 12, Action Energy, 1993 and *Energy Management Priorities – A Self Assessment Tool* Good Practice Guide 306, Action Energy, 2001.

Energy management matrix

Energy policy	Organising	Motivation	Information systems	Marketing	Investment
level 4					
Energy policy action plan and regular review have commitment of top management as part of an environmental strategy	Energy management fully integrated into management structure. Clear delegation of responsibility for energy consumption	Formal and informal channels of communication regularly exploited by energy manager and energy staff at all levels	Comprehensive system sets targets, monitors consumption, identifies faults, quantifies savings and provides budget tracking	Marketing the value of energy efficiency and performance of energy management both within the organisation and outside it	Positive discrimination in favour of 'green' schemes with detailed investment appraisal of all new-build and refurbishment opportunities
level 3					
Formal energy policy but no active commitment from top management	Energy manager accountable to energy committee representing all users, chaired by a member of the managing board	Energy committee used as main channel together with direct contact with major users	M&T reports for individual premises based on sub-metering, but savings not reported effectively to users	Programme of staff awareness and regular publicity campaigns	Same payback criteria employed as for all other investment
level 2					
Unadopted energy policy set by energy manager or senior departmental manager	Energy manager in post reporting to adhoc committee but the management and the authority are unclear	Contact with major users through adhoc committee chaired by senior departmental manager	Monitoring and targeting reports based on supply meter data. Energy unit has adhoc involvement in budget setting	Some adhoc staff awareness training	Investment using short-term payback criteria only
level 1					
An unwritten set of guidelines	Energy management the part-time responsibility of someone with only limited authority or influence	Informal contacts between engineer and a few users	Cost reporting based on invoice data. Engineer compiles reports for internal use within technical department	Informal contacts used to promote energy efficiency	Only low cost measures taken
level 0					
No explicit policy	No energy management or any formal delegation of responsibility for energy consumption	No contact with users	No information system. No accounting for energy consumption	No promotion of energy efficiency	No investment in increasing energy efficiency in premises

Remember to ensure that an efficient building design and building services strategy has been developed first, and then look at meeting the remaining demand using renewable energy.

New and Renewable Energy Systems

Many low carbon buildings meet some or all of their energy demand using renewable energy systems.

Renewable energy technologies can be divided into thermal and electrical systems. The following sections explore some of the major technologies and considerations for architects when incorporating them into new buildings or refurbishment projects. This section covers both domestic and non-domestic buildings.

The following commonly specified technologies may be appropriate to reduce the carbon dioxide emissions associated with individual buildings or with whole sites.

Thermal systems

Biomass heating and hot water systems can be used to reduce carbon dioxide emissions, and solar water heating can make a useful contribution to hot water demand, particularly in the summer. Ground source heat pumps are particularly attractive in areas without mains gas supplies.

However, using solar systems for heating is difficult because there is little solar energy available when the heating load is greatest. This is a fundamental issue that is often forgotten. It is even more of a problem for low energy buildings for which the heating season is reduced to a few months in the depth of winter. Unless expensive interseasonal storage is used, the best approach is to use simple passive solar techniques to capture whatever winter sun is available.

Passive solar design

At its simplest, a passive solar strategy involves facing the building south and concentrating the glazing on the south side. Care is needed to shade the south facing windows from the high-angle summer sun and to ensure that any north-facing windows still admit sufficient daylight.

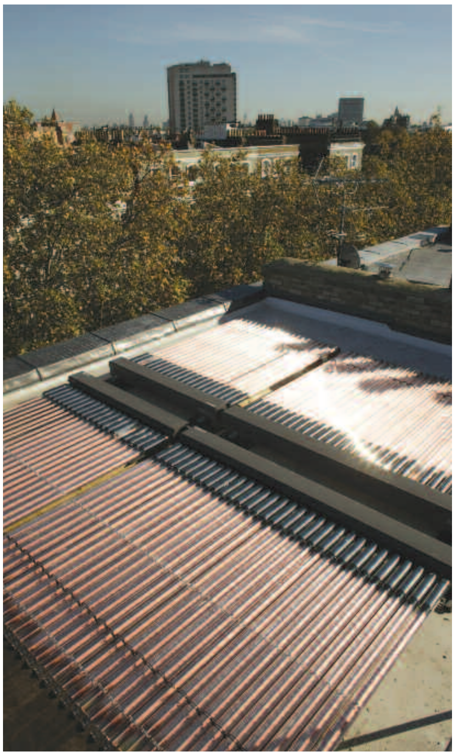
This direct passive solar strategy is optimized when the building fabric has the thermal capacity to absorb the solar gains and emit them later in the day.

Other passive solar systems, such as conservatories, trombe walls and roof-space collectors, have been much discussed over the years. They should all be approached with caution. Conservatories, in particular, are more often than not a source of increased fuel demand and emissions, because heat losses through the highly glazed fabric outweigh useful solar gains. This is especially true where conservatories are often used as an extra room and left open to the heated space.

Biomass heating

Biomass can be used as a fuel for a boiler that provides heating and hot water for a building. Biomass is usually wood and can come in the form of urban tree pruning, farmed coppices or factory waste. Other biofuels are also becoming available, for example biodiesel. When specifying biomass or other biofuel as a renewable fuel, care should be taken to identify where the fuel will come from, because long-distance transport of the fuel may involve significant carbon dioxide emissions.

Biomass heating can in theory be used for any building requiring heat but is best suited in low density situations (because of fuel supply and storage issues) and to buildings with block or district heating systems. Biomass in non-domestic buildings most commonly replaces gas or oil fuel in a boiler system.



Solar water heating installation on the Flagship Home, London courtesy of the Royal Borough of Kensington and Chelsea

Biofuel installations require frequent cleaning and this must be considered at the design stage to make sure that the system can be taken out of service for cooling and cleaning without interrupting the building's heating supply.

There are also questions about whether biomass is a 'scalable' fuel, i.e. whether there would be sufficient resources available within a reasonable distance if biomass was adopted on a large scale. The highway implications of accommodating large numbers of vehicle movements for fuel deliveries also need to be considered – biofuel prices are significantly lower for bulk deliveries involving large vehicles.

Government-funded grants are available for biomass installations; for more information see: www.lowcarbonbuildings.org.uk/micro/biomass

Solar water heating

Solar water heating systems use energy from the sun to heat water and are commonly used to offset some of a building's hot water demand. It is very effective for hot water production in most parts of the UK. Solar collectors are suitable for buildings with sufficient year-round hot water demand (such as homes or hotels) and retail units or offices with canteens or showers.

The system ideally uses a heat collector mounted on a southerly-facing roof and is connected to either a separate hot water cylinder or a twin-coil hot water cylinder (also connected to a standard boiler, for example). Solar collectors should be sized according to the building's average hot water demand.

There are two types of solar collectors – flat plate and evacuated tube. Flat plate collectors are popular for domestic systems, because of their lower cost. Evacuated tube collectors are more expensive but have better performance, especially in winter; they are particularly useful where available space is a factor, because a smaller collector area will be required. Solar collectors (especially the flat plate type) can easily be integrated into new roof structures or mounted on existing roofs.

In the domestic sector, a typical installation would have approximately 1m^2 of flat plate collector per person, with a solar storage volume of around 40 litres per m^2. Much thought needs to go into the siting of the hot water cylinder. Keeping the cylinder near the solar panel and any boiler will help to reduce heat losses from the pipes. It is also important that pipes are insulated along their entire length. In well insulated houses the losses can be a significant proportion of the total energy use and may add to overheating problems.

Government-funded grants are available for solar water heating; for more information see: www.lowcarbonbuildings.org.uk/micro/solartherm

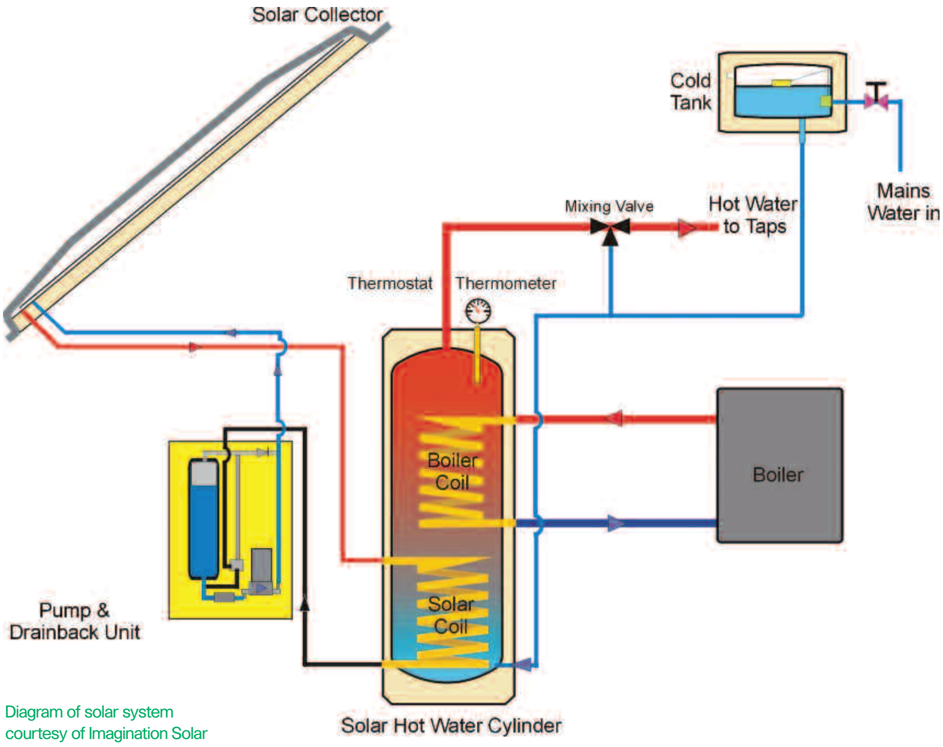


Diagram of solar system courtesy of Imagination Solar

1.5 MW community wind turbine at the Ecotec Centre in Swaffham. Photo courtesy of Keith Richards, TVenergy.org

Ground source heat pumps

Ground source heat pumps (GSHPs) are used to extract heat from the ground to provide space and water heating.They take in heat at a certain temperature and release it at higher temperature, using the same process as a refrigerator.

Heat pumps are often portrayed as a renewable energy source, but they are simply a relatively efficient way of using electricity to provide heating. Most heat pumps are electrically driven, although some systems use waste heat or burn fossil fuels instead.

The heat pump's efficiency (or coefficient of performance – CoP) is defined as the ratio of heat output to the quantity of energy used to drive the pump. A CoP more than 3 will deliver good energy and running cost savings.

The ground pipe systems can be:

- Horizontal, where a coiled pipes network is buried approximately two metres below ground level – this may require a large area of open space
- Vertical, where the pipes are placed in holes bored straight into the ground to a depth of approximately 150 metres, depending on the ground conditions and size of system.

Ground source heat pump systems can be used for individual houses and for larger residential and non-domestic buildings. Many systems can be used in 'reverse cycle' to provide summer cooling.

Once installed GSHPs require no maintenance for the ground pipes and standard maintenance for the mechanical equipment. Fuel cost savings can range from 25% up to 70%. Carbon dioxide emissions are typically comparable with those associated with a gas-fired condensing boiler delivering the same amount of heat.

Government-funded grants are available for GSHP installations; for more information see: www.lowcarbonbuildings.org.uk/micro/ground

Electricity generation

Renewable electricity can be supplied by photovoltaic (PV) panels or from wind turbines. On the right site it is sometimes possible to provide all the electrical needs of a building from these sources; however, if they are not linked to the electricity supply grid, expensive battery storage will be necessary.

In addition, there are many so called 'green' electricity tariffs. It is a good idea to support renewable electricity companies by subscribing to renewable electricity but green tariffs are not a substitute for dedicated renewable energy.[20]

The Government has announced that **'feed-in tariffs'** will be established in the UK from 2010. These are preferential tariffs which must be paid by energy supply companies for locally-generated electricity from renewable sources (e.g. PVs or wind power) that is supplied to them via the grid. The purpose of feed-in tariffs is to improve the viability of local renewable electricity generation and thus to increase demand for such systems, strengthen supply chains and reduce capital costs.

Wind power

Small scale wind power has been much promoted in response to planning standards that require minimum percentage contributions to building energy demand from renewable energy systems.

The output from a wind turbine is proportional to the cube of the wind speed – a halving of wind speed will decrease power by a factor of eight.

A good rural exposed site might have an average wind speed of 6 m/s. Speeds in urban areas are unlikely to be more than 1 or 2 m/s. Add to this the poor wind conditions immediately adjacent to a building and it can be seen that small building mounted turbines are probably not the best use of wind power. Designers should be very circumspect in their use.

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[20] See www.aecb.net/PDFs/green electricity illusion.pdf

Community scale turbines on windy sites are a much better prospect. Alternatively, if wind power is not feasible on site, it is possible for building occupants to own shares in large off-site turbines, which will show a much better return on investment.

Government-funded grants are available for wind power installations; for more information see: www.lowcarbonbuildings.org.uk/micro/wind

Photovoltaic electricity generation

Photovoltaic (PV) cells convert the sun's energy directly into electricity which, when converted from DC to AC, can be used to help meet a building's electrical power demands.

Although the UK's solar regime is not ideal compared with other sunnier parts of the world, PV can generate significant amounts of electricity and thereby reduce the carbon dioxide emissions associated with energy use in a building.

PV collectors should be:

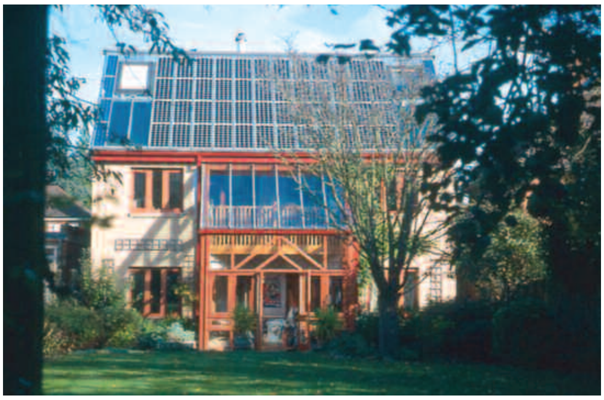
- Oriented between south-east and south-west
- Inclined to approximately 35° from the horizontal
- Free from overshadowing at any point during the day or during the year.

Of the commonly used low and zero carbon systems, PV is often calculated to be the most expensive per unit of energy saved. However, these systems integrate easily with other building services and require very little maintenance. They also provide a visible statement about a building's environmental credentials, and they do reduce both fuel costs and carbon dioxide emissions.

For commercial buildings, it is worth bearing in mind that the cost of PV panels is approximately the same as the cost of polished granite or aluminium cladding, neither of which generate useful energy.

A good PV system has the potential to deliver around 90 kWh of electricity per year per square meter of PV panels. In the domestic sector, a typical household using low energy lights and appliances might use 2,500 kWh/yr, so a PV installation of around 28 m^2 would be required to meet all their electrical needs over the year. At a cost of about £15,000 this is not a trivial investment, but PV remains the most attractive option for generating on-site renewable electricity.

Government-funded grants are available for PV installations; for more information see: www.lowcarbonbuildings.org.uk/micro/solarpv



4KW (approximately 30m^2) PV array yielding 3,000 KWh/yr at the Oxford Eco-House. Photo courtesy of Sue Roaf

Further Information

Accredited Construction Details and Enhanced Construction Details are available at www.planningportal.gov.uk

Two core CIBSE Guides are invaluable in low carbon building design:

- *Energy Efficiency*, Guide F
- *Sustainability*, Guide L

These are available from www.cibse.org

The Energy Saving Trust's Energy Efficiency Best Practice in Housing programme provides extensive guidance about energy efficiency and the use of renewable energy in new and existing housing – see www.energysavingtrust.org.uk

Grants for renewable energy technologies are available from the Low Carbon Buildings Programme – see www.lowcarbonbuildings.org.uk

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