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Capturing solar energy

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Capturing solar energy

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1 Introduction

This publication provides an overview of the available domestic and non-domestic solar system solutions, technologies and applications. It is principally directed at the designers of building services and others who may not be aware of the many solar options available and their possibilities. It will also help clients, building owners and facilities managers to understand the possibilities of using solar technology in their buildings.

Solar radiation is one of the most versatile and plentiful sources of renewable energy at our disposal. It can be captured and used both directly and indirectly, and can provide a significant contribution to the reduction of carbon emissions from fossil fuels. Solar solutions offer additional opportunities to meet the requirements of planning policies and building regulations.

This publication considers the technologies available for capturing solar energy and the application of these technologies. It also highlights some of the main design and installation issues and commissioning and maintenance requirements, and provides information on regulations and costs. In order to encourage the inclusion of solar applications into building design the UK government has been, and is, providing a range of incentives and these are summarised.

A summary of solar collector technologies and their typical uses is shown in Table 1.

Table 1: **Summary of solar collector technologies and typical applications**

Technology	Application						
	Commercial and domestic hot water (DHW) and heating	Pre-heating of ventilation air	Cooling using absorption chillers (domestic or commercial)	Swimming pool heating (indoor)	Swimming pool heating (outdoor)	Electricity generation	Other
Flat plate collector (glazed, liquid-based)	✓			✓	✓[note 1]		
Flat plate collector (glazed, air-based)		✓					
Flat plate collector (unglazed, liquid-based)					✓		✓[note 2]
Perforated plate		✓					✓[note 3]
Evacuated tube collector	✓		✓	✓			
Photovoltaic cells						✓	

Notes: [1] Technically possible but expensive; [2] pre-heating water for fish farms, car wash plants etc. [3] crop drying

2 The use of solar energy systems

Solar energy systems have been used successfully in the UK for the last 30 years. However, with the level of solar radiation received (the maximum is about 1 kW/m^2) and its seasonal variation, the reality is that solar systems will almost certainly be unable to meet the total energy demand of a building in the UK at a viable cost. Therefore, solar energy systems for buildings are rarely used on their own and are usually installed alongside conventional systems. However, solar energy systems should not be regarded as top-up systems as the energy supplied by them will always need to be used first. It is the conventional energy sources that should be regarded as the top-up, as they will only come into play when the solar system cannot meet demand.

The orientation of the building is key to maximising the amount of solar energy captured. The ideal would be for the building to have a south-facing roof on which the solar collector can be placed. If the collector faces in any direction other than due south its efficiency is reduced but it will still function well if facing southeast or southwest, and may produce acceptable results when facing east or west. Shading of the building, due to neighbouring buildings or trees for example, will also cause the efficiency of the solar collector to be dramatically reduced (see section 3 for more information on shading).

Even if the above considerations are favourable for the use of a solar energy system in a specific building, there is another issue that needs to be addressed before deciding upon its use. This is the need to ensure that the building is as energy efficient as possible, especially in terms of its insulation, airtightness and controls. The cost of improvements to these aspects will increase overall expenditure but will be rapidly offset by the reduction in fossil fuel bills.

In order to reduce the demand of a building for energy from non-renewable sources, consideration should always be given to passive solar measures. These exploit the building's orientation, shape, construction materials, fenestration, internal room arrangements and external landscaping, in combination with other energy efficiency measures, to reduce the energy demand (see section 4.1 for more information).

Even if the client does not wish to install solar technology immediately it may still be possible to produce a design that facilitates retrofitting at a later date, such as by ensuring that the roof faces south.

When considering solar energy systems, there are three main ways in which the energy can be used within a building:

- by collecting it via a solar panel and using it to produce hot water and, possibly, heating or warm air for buildings, or warm water for swimming pools (see sections 5.1, 5.2 and 5.3)
- by collecting it via a solar panel and using it to drive absorption or adsorption chillers for air conditioning (see section 5.4)
- by collecting it via photovoltaic (PV) cells and using it to produce electricity (see section 5.5).

3 Solar radiation in the UK

3.1 How much solar energy does the UK receive?

Each square metre in the UK receives about 1000 kW·h of solar radiation annually and the peak solar irradiation is around 1 kW/m^2. This is substantial but only about 50% of the annual solar radiation received at the equator because of the higher latitude and also because the UK experiences more cloud cover. As the radiation from the sun passes through the earth's atmosphere some of it is absorbed, scattered and reflected by water vapour, clouds, dust etc. The proportion of this scattered radiation that reaches the earth's surface is known as diffuse radiation as it appears to come from all over the sky. The rays coming straight from the sun are known as direct radiation. In the UK approximately 50% of the total annual radiation is diffuse. Manufacturers of solar systems for the UK and western Europe have developed products that absorb not just direct radiation, but also as much diffuse radiation as possible so that they are still able to capture energy on cloudy days. Figure 1 shows the variation in average annual solar irradiation over the UK and Figure 2 shows the amount of direct and diffuse irradiation available in western Europe.

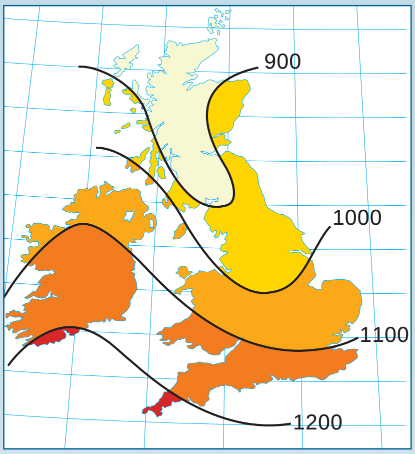


Figure 1:
Annual average solar irradiation (kW·h/m^2) on a 30° incline facing due south

3.2 How does the amount of solar radiation vary?

The amount of solar radiation available is determined by geographical location but it also varies over the year. In the UK the monthly solar radiation available on a horizontal surface in December is only about 10% of that available in June, with the ratio improving slightly for inclined surfaces. Table 2 shows the average daily irradiation per month on a south-facing plane inclined at 30° to the horizontal for London, Manchester and Edinburgh.

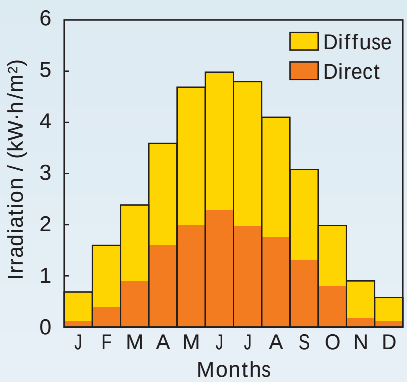


Figure 2:
Daily amounts of direct and diffuse radiation (kW·h/m^2) available in Europe

3.3 How much does orientation and tilt of a surface matter?

The maximum total annual solar radiation is usually at an orientation due south and at an angle from the horizontal equal to the latitude of the site minus approximately 20°, (e.g. 30° in southern England increasing to almost 40° in northern Scotland). To maximise the solar irradiation received in summer the angle from the horizontal should be decreased by 10° whereas for maximum winter irradiation it should be increased by 10°. The variation in maximum total annual solar irradiation across the UK is relatively small; for example the maximum total annual solar irradiation for Eskdalemuir and London are 920 kW·h/m^2 per year and 1045 kW·h/m^2 per year, respectively. The precise tilt and orientation are not critical (see Figure 3) as orientations between SE and SW and tilts of 10–50° to the horizontal will receive over 90% of the maximum annual energy. An unobstructed vertical surface in any

Location	Daily mean irradiation (kW·h/m^2) for stated month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
London	1.11	1.89	2.74	4.03	4.78	5.03	4.98	4.68	3.39	2.45	1.14	0.93
Manchester	1.11	1.81	2.67	4.05	4.78	4.77	4.86	4.53	3.46	2.24	1.38	0.88
Edinburgh	0.83	1.57	2.67	3.77	4.75	4.81	4.70	4.03	3.05	1.80	1.09	0.51

Table 2:
Monthly mean daily total irradiation (direct plus diffuse) on south-facing plane inclined at 30° to horizontal for London, Manchester and Edinburgh (source: CIBSE Guide A[20], Tables 2.27–2.29)

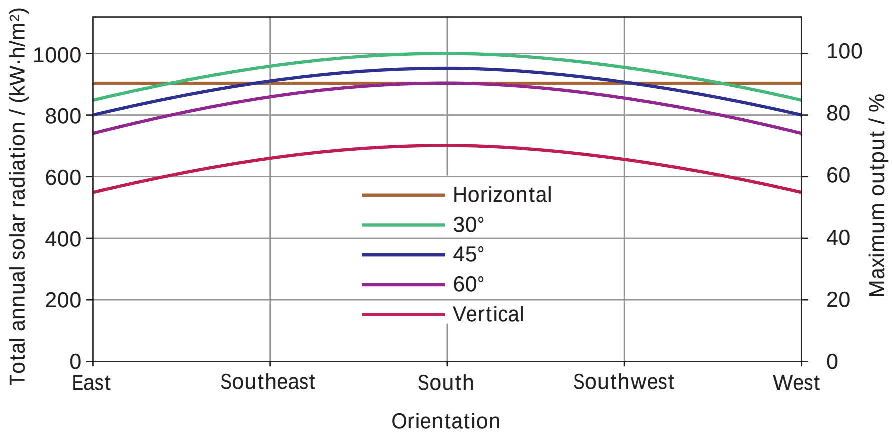


Figure 3:
Effect of tilt and orientation on energy generation (based on data for SE England)
(source: CIBSE TM25[6], Figure 5)

direction between SE and SW (i.e. within ±45° of due south) will receive approximately 70% of the maximum annual energy.

3.4 How important is local climate and shading?

The performance of a solar energy system is mainly dependent on the amount of available solar radiation so local climate, such as the occurrence of fog or mist and exposure to wind, can be significant. If the site or building is shaded it may not be suitable. Not only should the site or building be as free from shading as possible, but care should be taken to ensure that there are no plans for the development of adjacent sites that might substantially shade the site in the future.

Avoiding shading is critical for systems using photovoltaic cells. Even minor shading can result in significant energy loss. This is because individual photovoltaic cells are connected together in series to provide the required voltage. The cell receiving the lowest illuminance will determine the operating current of the whole series string.

Shading rules of thumb

- Minimise shading during the middle six hours of the day
- Shading will occur if there is an obstruction above a line drawn at 20° from the horizontal in the direction of the sun
- Deciduous trees provide more shade in summer (an important consideration in passive solar design) and bear in mind that trees grow
- Avoid self-shading, i.e. shading by other parts of the building

4 Solar collector technology

Passive solar design measures should be considered to reduce the demand of a building for energy from 'traditional' sources before active solar collector technologies are considered (see section 4.1).

There are then two main ways actively to exploit the sun's energy in climates such as that of the UK:

- using thermal collectors, either flat plate or evacuated tube, to absorb the sun's radiation to produce hot water or air (see section 4.2)
- using photovoltaic cells which utilise the sun's light to create an electric current and generate electricity (see section 4.3).

Other collectors such as parabolic troughs and dishes, that capture only direct solar radiation, are used effectively in countries such as Spain, Australia and New Zealand but are inefficient in the UK.

4.1 Passive solar design

The term 'passive solar design' encompasses a variety of techniques used to trap heat within a building during the winter months while avoiding overheating during the summer months. It integrates a combination of building features which can markedly reduce the need for mechanical heating and electric lighting. New construction offers the greatest opportunity for incorporating passive solar design and it should be considered as early as possible in the design process.

There are five main elements involved in passive design:

- *Large area of glazing*: to allow as much sunlight as possible into the building (usually facing within 30° of due south and not shaded during the day in the heating season).
- *Internal surfaces*: that absorb solar radiation well (usually darker colours).
- *Thermal mass*: to store the heat and prevent overheating (e.g. masonry wall, floor, phase-change materials or a body of water).
- *Distribution system*: to extract the stored heat from the thermal mass and circulate it throughout the building (a strictly passive design will only use conduction, convection and radiation, but fans, blowers and ductwork are also used).
- *Control systems*: to prevent under- and overheating. Roof overhangs can block direct sunlight during the summer months when the sun is high in the sky but allow it to penetrate the building during the winter months when the sun is lower. Other systems used include differential

thermostats, vents and dampers, low-emission blinds and awnings. Deciduous bushes and trees are also sometimes used in front of the building; during the summer months they block much of the direct sunlight, but allow it to penetrate during the winter months when the leaves have fallen.

There are three types of passive solar design:

- direct gain systems
- indirect gain systems
- isolated gain systems.

These are summarised in Table 3 (see page 8). For more information on passive design see CIBSE TM35[1], TM37[2], section 2.2 of CIBSE Guide B[3], and CIBSE AM10[4].

4.2 Solar thermal collectors

There are two main types of thermal collector:

- flat plate
- evacuated tube.

The key element of both flat plate and evacuated tube collectors is the absorber. This is the surface, usually flat, on which the solar radiation falls and which incorporates tubes or channels through which the heat transfer fluid can circulate. Dark coloured, matt surfaces will absorb more radiation than light, polished ones, so metal absorber plates are usually coated to improve absorption. The coating may be non-selective (usually matt black paint) or selective, to reduce the emission of thermal radiation.

4.2.1 Flat plat collectors

There are a variety of types of flat plate collector including:

- *glazed*: liquid and air-based
- *unglazed*: liquid and air-based.

Table 4 (see page 9) summarises the principal characteristics and applications for each of these types of flat plate collector.

When comparing and selecting flat plate collectors care needs to be taken as the collector area given by manufacturers may be the gross area, the absorber area or the aperture area, as shown in the adjacent box.

Area measurements used for flat plate collectors

When comparing and selecting flat plate collectors, manufacturers use different definitions of area. These are illustrated below.

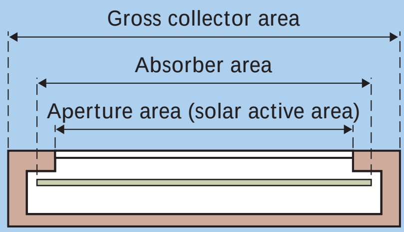


Table 3:
Summary of types of passive solar systems

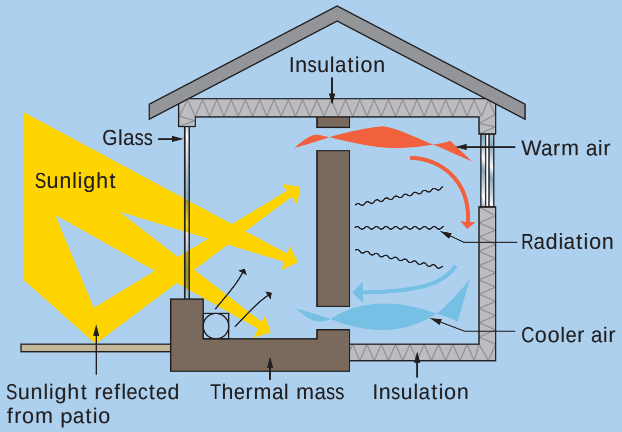
Direct gain

Description: solar energy enters the living space directly through glazing, is converted to heat at absorbing surfaces and stored by thermal mass which releases the heat by conduction, radiation and convection; the thermal mass may be provided by a dividing wall.

Generally simple and low cost.

Potential problems: temperature swings and glare.

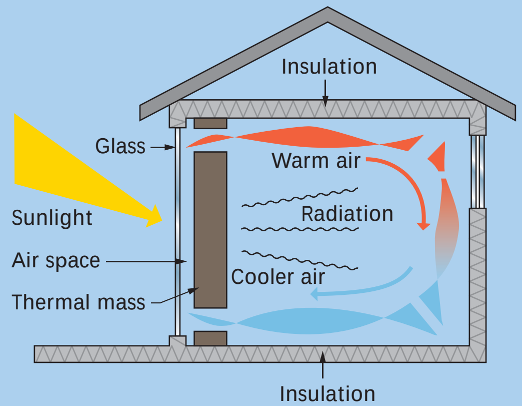
Application: most appropriate for domestic or other continuously occupied buildings. Not appropriate for retrofit.



Indirect gain

Description: the thermal mass is situated close to south-facing glazing, to form what is known as a 'Trombe wall'. A chimney effect is created in the relatively narrow gap between the glass and the wall so providing vents at the top and bottom of the wall can help to distribute the warmed air around the building by convection. Reverse circulation at night must be avoided. There will be a relatively long time delay before heat is emitted, typically 8 to 10 hours.

Application: most appropriate for non-domestic, continuously occupied buildings; not appropriate for retrofit.



Isolated gain

Description: solar radiation is collected in a separate space, e.g. a conservatory, that is then selectively closed-off or opened to the rest of the building. The efficiency will be lower than for a 'Trombe wall' system because of the greater surface area. It will be necessary to provide shading and ventilation of the sunspace to prevent overheating in summer.

Application: domestic or commercial buildings; appropriate for retrofit.

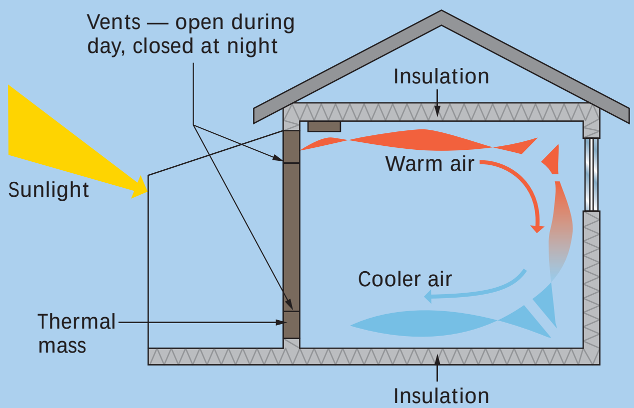


Table 4:
Flat plate collector types and applications

Glazed (liquid-based) type

Construction:

- transparent cover (usually iron-poor safety glass, but can be acrylic, Teflon® or Tedlar®)
- absorber plate (metal or polycarbonate, may have a selective coating)
- insulation
- weatherproof casing (aluminium, galvanised steel or glass-fibre-reinforced plastic)

Relatively heavy and needs protection from freezing and overheating

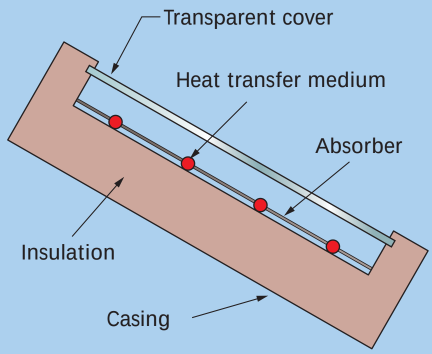
Typical output temperature: 30 to 80 °C

Uses:

- heating, domestic hot water (dwellings and commercial buildings)
- indoor swimming pools (where heat is required throughout the year)

Wide range of mounting possibilities

Suitable for new build and retrofit



Glazed (air-based) type

Construction:

- similar to glazed (liquid-based) except that air is passed over the collector plate
- circulation can be fan driven or by natural convection

Lighter than liquid-based collectors and freezing not a problem

Less efficient than glazed (liquid based)

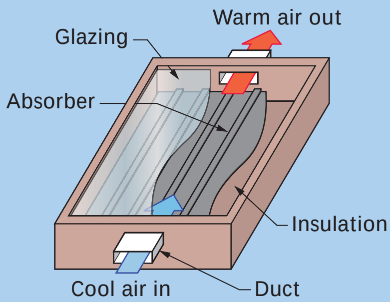
Output temperature: 20 to 50 °C

Uses:

- primary use pre-heating ventilation air
- may also provide some DHW heating

Mainly domestic

Usually mounted on the roof



Unglazed (liquid-based) type

Construction:

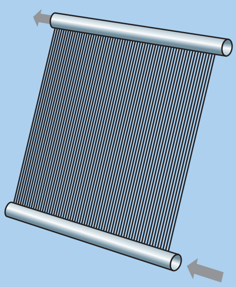
- plastic absorber with integral header pipes (usually polypropylene or PVC)
- can be rigid or in the form of a flexible mat
- no glazing, insulation or casing

Operates at low temperature so designing to maximise heat gain is more important than minimising heat loss

Output temperature: < 30 °C

Uses:

- outdoor swimming pools
- outdoor car wash
- outdoor pre-heating water for fish farms



Unglazed (air-based), perforated plate (or transpired air collector) type

Construction:

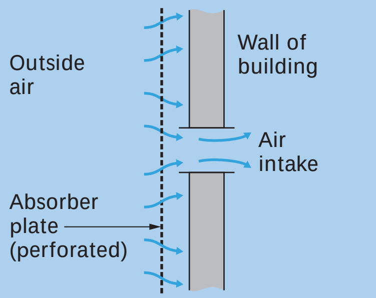
- absorber is industrial grade cladding made from perforated heat absorbing material
- outside air passes through the small holes and is warmed before entering the building
- dampers are required to shut-off the system in warm weather and prevent reverse circulation

Output temperature: can raise the air temperature by 20 to 30 °C

Uses:

- pre-heating ventilation air (especially for large buildings such as warehouses with a high ventilation load)
- crop drying

Usually installed as wall cladding



4.2.2 *Evacuated tube collectors*

Evacuated tube collectors are generally more efficient than flat plate collectors, but are also more expensive as they are more sophisticated devices. Their increased efficiency results from mounting the absorber in an evacuated and pressure-proof glass tube which reduces conductive and convective losses. They work efficiently at low radiation levels and with high absorber temperatures and can provide higher output temperatures than flat plate collectors. Evacuated tube collectors can be used in applications where the demand temperature is 50–95 °C or in colder climates.

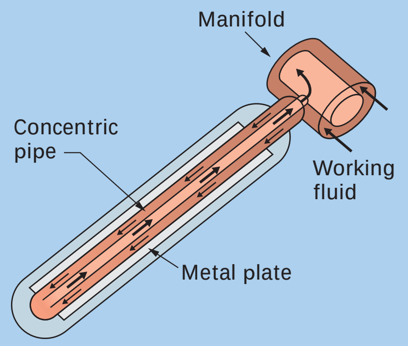
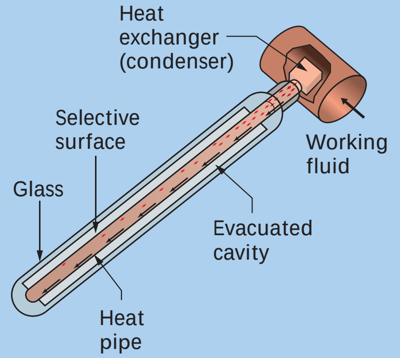
There are two main types of evacuated tube collectors:

- direct-flow (where solar primary fluid flows through the absorber)
- heat pipe.

Table 5 summarises the principal characteristics and applications for each of these collector types.

A collector is made up of a series of tubes connected into a top manifold through which the solar system primary fluid circulates. For heat pipe evacuated tube collectors the connection may be ‘wet’, where the heat

Table 5:
Evacuated tube collector types and applications

Direct-flow evacuated tube collector		
Construction: • metal fin or cylindrical absorber bonded to a U-tube or pair of concentric pipes sealed at one end • primary fluid circulated through the pipes from a manifold at the top • the absorber and pipes are sealed in an evacuated glass tube Some tube collectors can be rotated so their absorber can be angled to optimise performance. Output temperatures: 50–95 °C	Uses: • DHW heating, domestic and commercial • swimming pool heating (indoor) • cooling (using absorption chillers or desiccants) Wide range of mounting possibilities from horizontal to vertical surfaces	
Heat pipe evacuated tube collector		
Construction: • metal fin or cylindrical absorber bonded to a sealed copper tube containing a fluid which evaporates when heated (the heat pipe) • vapour rises to a heat exchanger where heat is transferred to the solar system primary circuit, condensed fluid flows back down the heat pipe. Heat pipe collectors must be inclined at an angle greater than 25° to the horizontal. Output temperatures: 50–95°C	Uses: • DHW heating, domestic and commercial • swimming pool heating (indoor) • cooling (using absorption chillers or desiccants)	

exchanger is in direct contact with the solar primary fluid, or 'dry', where the connection is made by heat conducting material. A 'dry' connection allows individual tubes to be replaced without draining the solar primary system.

4.2.3 How much energy can a solar thermal collector provide?

The efficiency of a solar thermal collector is the useable thermal energy divided by the received solar energy. It depends on a number of factors including the type of collector, the spectral response of the absorbing surface, the collector insulation and the temperature difference between the collector and the ambient air.

As a collector heats up, its efficiency will decrease due to an increase of heat loss through infrared radiation and convection. A cooler collector is therefore more efficient, but the lower temperature of the heat it collects will be less useful.

Plotting efficiency versus the temperature difference between the mean collector temperature and the ambient temperature gives a collector efficiency curve as shown in Figure 4. The efficiency when the collector is at the same temperature as the ambient air is called the 'conversion factor'. For the collector described in Figure 4 the conversion factor is 80%. The conversion factor is also known as the 'optical efficiency' and indicates the proportion of received solar energy available after transmission and absorption losses. The heat loss is indicated by the 'heat loss coefficient', given in $W \cdot m^{-2} \cdot K^{-1}$, and the temperature difference between the absorber and its surroundings. Above a specific temperature difference (127 °C for the collector described in Figure 4), the heat loss is equal to the energy yield of

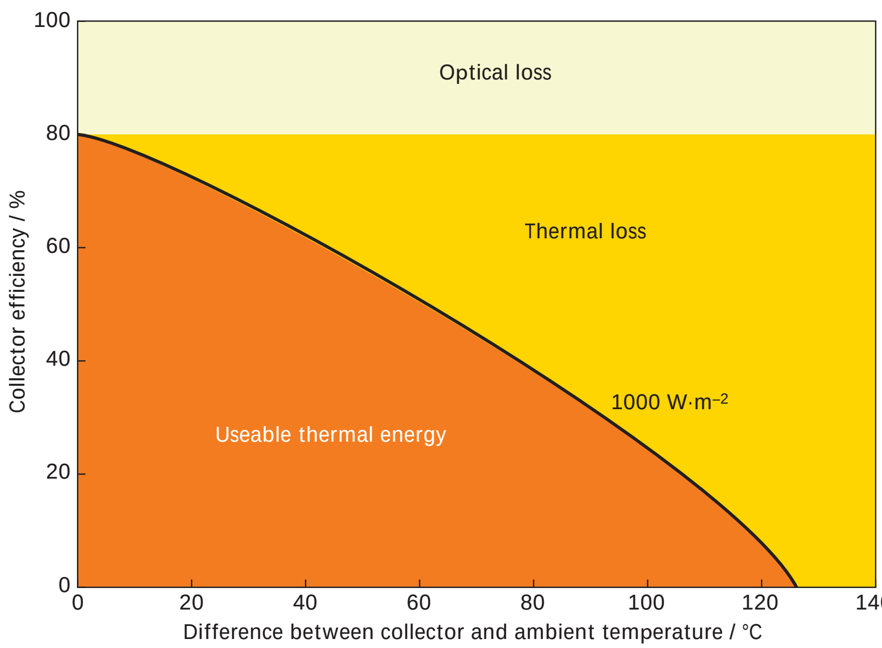


Figure 4:
Solar thermal collector efficiency curve

Solar collector efficiency

The performance of a collector is measured according to the test standard BS EN 12975[5] by means of a plot of efficiency versus temperature difference and statistical curve fitting.

The efficiency is given by the equation:

$$\eta = \eta_0 - a_1 \frac{(T_m - T_a)}{G} - a_2 \frac{(T_m - T_a)^2}{G}$$

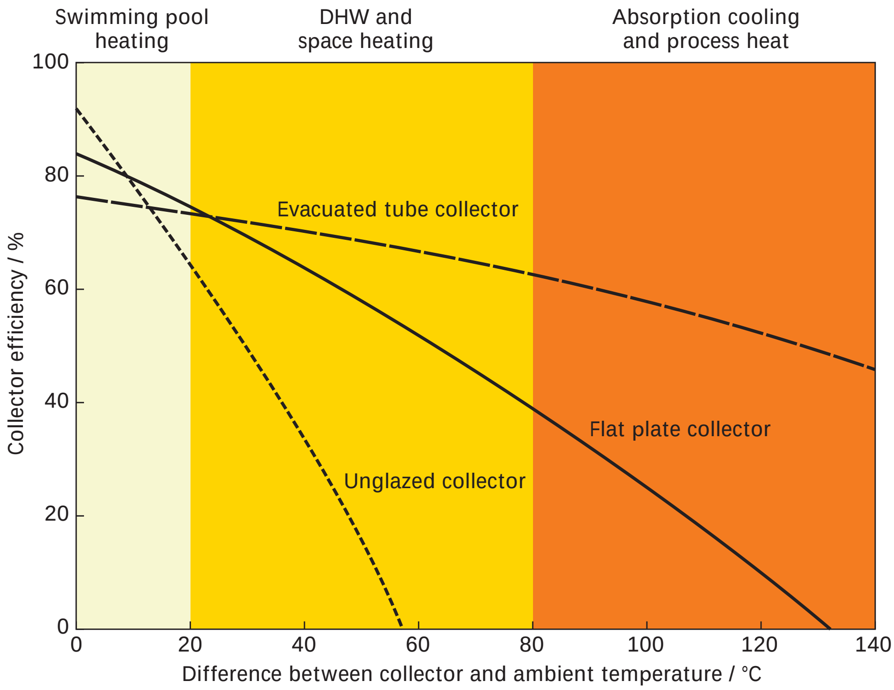
where η is the collector efficiency, η_0 is conversion factor (i.e. efficiency when the collector is at the same temperature as its surroundings), a_1 is the heat loss coefficient ($W \cdot m^{-2} \cdot K^{-1}$), a_2 is the temperature dependence of the heat loss coefficient ($W \cdot m^{-2} \cdot K^{-2}$), T_m is the mean collector temperature (°C), T_a is the ambient temperature (°C) and G is the solar irradiance ($W \cdot m^{-2}$).

Values for η_0 and the heat loss coefficients a_1 and a_2 from the test are provided by the manufacturer as standard performance data for solar collectors.

the collector so no useful heat is delivered. A good collector will have a high conversion factor and a low heat loss coefficient.

The choice of collector for an application depends upon the resultant temperature range desired. Other considerations include the amount of radiation expected, weather conditions and the space available.
Flat plate collectors are more commonly used than evacuated tube collectors. They are usually cheaper but, as the efficiency is lower, a larger collector area is needed to provide equivalent output. Figure 5 shows the efficiency and temperature ranges of various collectors.

Figure 5:
Efficiency and temperature ranges for various types of collectors

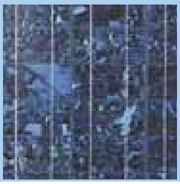
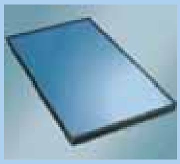


4.3 Photovoltaic cells

Photovoltaic (PV) cells consist of one or two layers of a semiconductor material, usually silicon. When the sun's rays hit the cell, an electric field is generated across the layers. PV cells do not necessarily require direct sunlight in order to operate as they will still work with the diffuse light of a cloudy day. However, the greater the intensity of sunlight hitting the cells, the greater the flow of electricity.

The three most common cells types used with buildings (all based on silicon) are:

- monocrystalline
- polycrystalline
- thin-film amorphous.

Property	PV cell type		
	Monocrystalline silicon	Polycrystalline silicon	Thin film amorphous silicon
Appearance			
Cell efficiency at standard test conditions[1]	15–17%	14–15%	8–12%
Module efficiency	13–15%	12–14%	5–7%
Area of modules required per kW_p[2]	7 m^2	8 m^2	16 m^2
Area per kW_p[2] of building materials incorporating PV cells	Glass–glass laminates: 8–30 m^2 (depends on cell spacing)	Glass–glass laminates: 10–30 m^2 (depends on cell spacing)	Solar metal roofing: 23.5 m^2 Glass–glass laminates 25 m^2
Advantages/disadvantages	Most efficient but highest cost	Cheaper than monocrystalline but slightly less efficient	Considerably cheaper but about half the efficiency of monocrystalline Offers the widest range of options for integration into building elements

Notes: [1] Standard test conditions (STC) are 25 °C, light intensity of 1000 W/m^2 and air mass (spectral power distribution) of 1.5 and a cell temperature of 25 °C; [2] kWp = peak output power (kilowatts) (solar PV products are rated by their output power at STC)

Table 6:
Properties of common types of PV cell

The properties of these types are shown in Table 6. Other types of PV cell available include 'hybrid' cells which combine both monocrystalline and thin-film silicon and ones using alternative materials such as cadmium telluride (CdTe) and copper indium diselenide (CIS).

A single monocrystalline PV cell (100 cm^2) typically produces a voltage of about 0.5 volts at a current of up to 3 amps, i.e. a peak power of about 1.5 W_p. A number of cells, typically 36 or 72, are connected in series to form a module that produces a higher, more useful, voltage than a single cell. The cells are encapsulated between a transparent front cover and a backing sheet to protect them, and the cells are hermetically sealed. Figure 6 illustrates the construction of a typical crystalline silicon module. The power output for a PV module depends on its size and type of cells but is typically between 100 and 200 W_p.

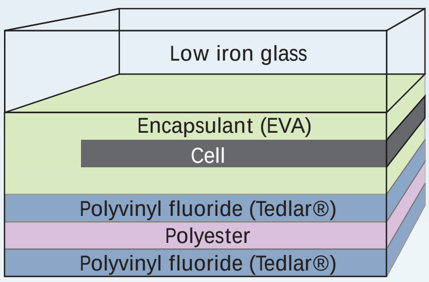


Figure 6:
Construction of typical crystalline silicon module

Thin film cells are made by vapour deposition of a very thin layer of photosensitive material on a substrate such as glass, stainless steel or plastic, which is scribed to form separate cells and then encapsulated in plastic.

For more information on PV cells see section 2 of CIBSE TM25: *Understanding building integrated photovoltaics*[6].

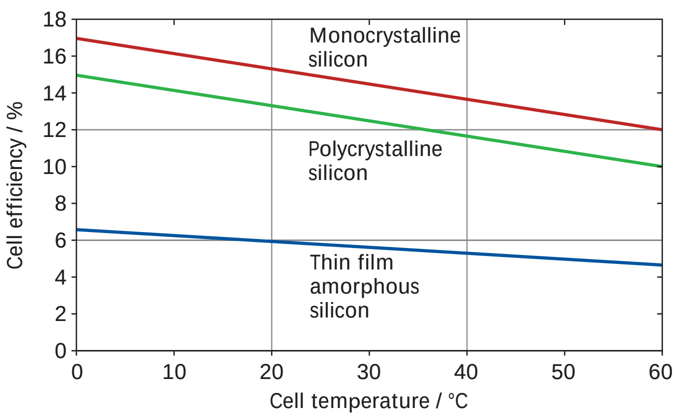
For PV cells, temperature is an important consideration; the efficiency of cells falls as their temperature rises (see Figure 7). Ventilating the modules should be considered when designing the installation.

PV systems are particularly suited to applications where there is an electricity demand during the day, such as offices, retail premises and schools. Also, PV systems may be connected to the grid so that any excess electricity can be exported.

Figure 7:

Cell efficiency as a function of temperature

(Source: CIBSE TM25[6])



5 Applications for solar energy

The most common use of thermal solar energy in the UK is for heating domestic hot water (DHW) and it can also be used to heat water for industrial processes (up to about 80 °C). Providing swimming pool heating is a particularly efficient application because of the low water temperatures required. The availability of solar radiation is out of phase with the demand for space heating (see Figure 2) so a solar system large enough to provide a significant amount of energy in winter will produce much more energy than is likely to be required in summer. Liquid-based solar heating systems are unlikely to be cost effective for providing space heating unless there is a demand for the energy produced in the summer, e.g. to provide solar cooling, or the energy can be stored using, for example, a borehole or underground thermal storage system. Air-based solar systems, however, can be an economical way to pre-heat ventilation air. This section will consider water heating, air heating, solar cooling and the use of photovoltaics to produce electricity.

5.1 Water heating

5.1.1 System types

Solar domestic hot water heating systems all work on the same principle; water from the cold supply feeds dedicated pre-heat solar storage, which is then heated by the solar collectors. The pre-heated water is then heated to the required draw-off temperature by a back-up boiler or immersion heater.

The type of system is identified by the layout of the solar primary circuit, see Figure 8.

Where the solar collectors can be mounted below the level of the solar store circulation will occur by the thermosyphon effect (see Figure 8(a)). This system is often used in Mediterranean countries. In the UK, however, the solar collectors are usually mounted on the roof so circulation in the solar primary circuit is pumped. The operation of the pump is usually controlled by a differential temperature controller. This compares the temperature at the collector panel outlet with the temperature of the water in the solar store adjacent to the heat exchange coil and switches the pump on when there is sufficient thermal gain to offset the pump and transfer losses. It also ensures that heat is not left unnecessarily in the collector and that heat is not accidentally pumped out of the solar store.

The solar water circuit can be direct or indirect. In a direct circuit the water to be heated is circulated directly through the solar collectors as shown in Figure 8(b) whereas in an indirect system a heat exchanger ensures that the

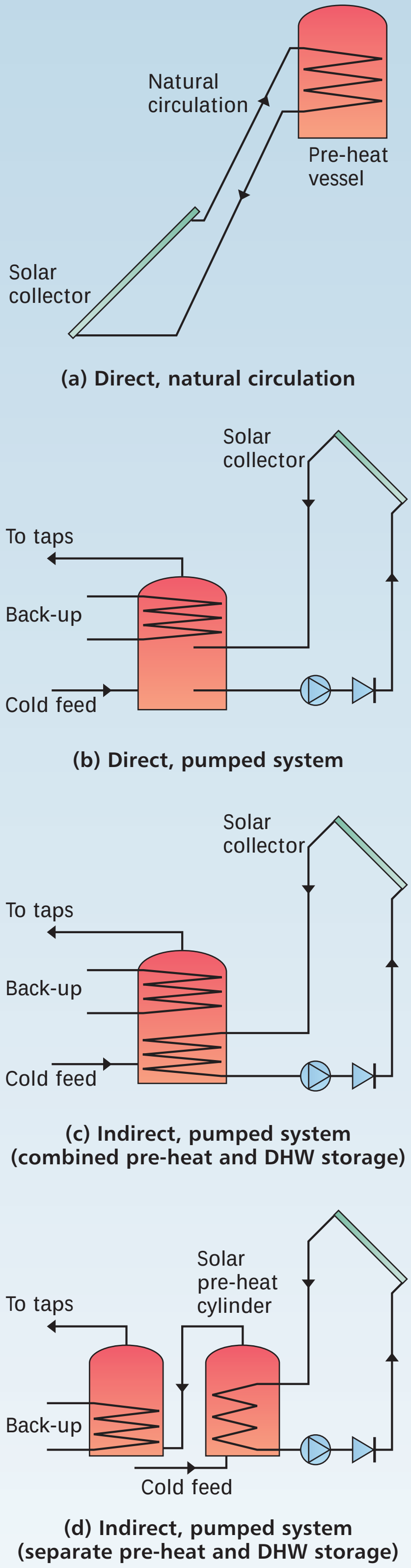


Figure 8:
Basic schematics of solar water heating circuits

solar primary fluid is separated from the secondary side of the system (see Figure 8(c)). The majority of systems in the UK are indirect as one of the advantages of these systems is that anti-freeze and anti-corrosion liquids can be added to the fluid in the solar primary circuit. Direct solar water heating systems are not generally compatible with unvented storage cylinders as thermal stores, i.e. where mains pressure water passes through a heat exchange coil and is heated by the static water in the store. The potential for the build-up of scale in the collector circuit should also be considered.

Dedicated solar storage is needed because solar energy input may not coincide with the demand for hot water. For domestic systems the solar pre-heat storage and the store heated by the back-up are usually combined as shown in Figure 8(c). For larger installations the system may be designed with two or more pre-heat and/or storage tanks in series, with sensors set to measure the return temperature of the water in the first tank and either re-circulate it through the collector or pass it on to the next tank (see Figure 8(d)). The temperature differential across the collector will be between only 6 and 15 K, so the heat exchange coils must be designed for a low temperature differential.

5.1.2 Design issues

Solar primary systems are subject to extreme temperatures. Collector temperatures may range from –20 °C on clear winter nights to over 200 °C for flat plate collectors and 350 °C for evacuated tube collectors if there is continuous high solar radiation without heat consumption (i.e. stagnation temperatures when there is no fluid flow). A high performance collector can easily capture enough heat to convert the circulating fluid to steam under significant pressure. Solar water heating systems have to be designed to cope safely with these conditions. Issues which must be considered during the design include:

- high temperatures
- control of expansion and overpressure as a result of high temperatures
- prevention of steam or scalding water reaching the taps
- protection from freezing of fluid in the collector or other parts of the solar primary circuit
- control of *legionella* bacteria.

High temperatures

All the materials used in the system must be capable of withstanding the full range of temperatures to which they will be exposed. This means that all the materials close to the solar collectors must be able to withstand the collector stagnation temperature and that the other materials in an indirect system can withstand temperatures up to 150 °C.

Control of expansion and overpressure as a result of high temperature

Expansion in the solar primary circuit occurs from temperature rises within the fluid during both normal and fault conditions, and is an issue of safety. To comply with the requirements of section 4.1.4 of BS EN 12976[7], the solar primary system should be 'hydraulically secure', which means it should be designed so that:

- there is no release to atmosphere of any high temperature fluid (vapour or liquid) under any operating conditions
- there is auto-resumption of normal operation after stagnation without end-user intervention.

In a sealed indirect system this is achieved either by a fully-filled, pressurised system where the fluid expansion is accommodated using an expansion vessel with an internal membrane as shown in Figure 9(a), or by isolating the heat source by allowing the fluid to drain from the collectors into a drain-back vessel with an air pocket whenever the pump is switched off as shown in Figure 9(b). Solar expansion vessels are considerably larger than those used with traditional sealed heating systems of a similar working volume because under stagnation conditions the fluid in the absorber vaporises, so the expansion vessel has to be large enough to contain the primary fluid content of the collector as well as the thermal expansion volume of the system. They also need to be rated for at least 100 °C and be able to tolerate antifreeze.

A fully-filled pressurised system will also need at least one pressure relief valve to act as a safety mechanism. Systems in which the foreseeable pressure in any part of the system is expected to exceed 50 Pa (0.5 bar) and where water temperatures will exceed 110 °C must meet the requirements of the Pressure Equipment Regulations 2001[8]. The Regulations call for a minimum of 'sound engineering practice' to be used but in many cases, particularly where large volumes or high pressures are present, certain extra essential safety requirements must be met. Drain-back systems operate at lower pressures and temperatures.

Prevention of steam or scalding water reaching the taps

Children and the infirm are at risk of scalding at water temperatures above 38 °C and for most adults exposure to water at 60 °C for only a few seconds can be hazardous. An efficient solar heating system in the UK is easily capable of producing secondary water at scalding temperatures and of reaching up to 100 °C where the solar storage capacity is relatively small. Where the solar system is designed to be 'hydraulically secure' the solar heat supply can be safely switched-off so there will be full thermostatic control of the secondary water temperature. Where the secondary water temperature cannot be fully

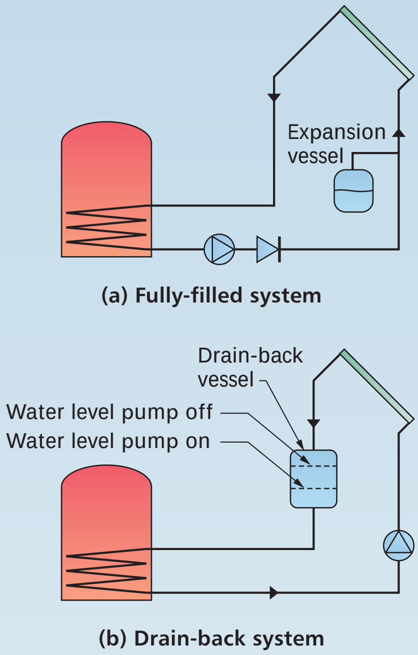


Figure 9:
Basic schematics of typical hydraulically secure systems

controlled the risk of scalding can be reduced by using a thermostatic mixing valve to reduce the DHW outlet temperature.

Freezing

In an indirect solar primary circuit, antifreeze (usually polypropylene glycol) is added to the fluid, along with corrosion inhibitors, to prevent freezing. Antifreeze is also sometimes used for extra security in a drain-back system even though the fluid can be drained from the collectors and other external components by switching-off the pump. In a direct system, however, as antifreeze cannot be used, it is crucial that the solar collectors and other system components can either withstand freezing or are protected against freezing. Some systems use freeze-tolerant materials that can accommodate the expansion caused by freezing.

Control of Legionella bacteria

There is an increased risk of bacterial growth in water held at temperatures between 20 °C and 46 °C for prolonged periods. The temperature of solar pre-heated water is not fully controlled and, as it is possible that these conditions can occur, all pre-heated water should be designed to pass through an auxiliary heat source capable of heating it to at least 60 °C (at all foreseeable flow rates) before it is delivered to the taps.

As this brief discussion of the design issues shows, solar water heating system design is complex. Detailed guidance can be found in the Domestic Building Services Panel's *Solar heating: design and installation guide*[9]. Care should be taken to ensure that the system is designed to control the risk of *Legionella*, and to satisfy the requirements of HSE Approved Code of Practice L8[10].

5.1.3 System sizing

The system should be designed to supply 100% of the building's hot water demand during the summer months to gain full benefit from the installation. The system will not be able to supply the maximum hot water demand in the winter months but should still be able to make a contribution. Table 7 gives an indication of the likely hot water demands for commercial and domestic buildings. For more detailed information on establishing the hot water demand of a commercial building see CIBSE Guide G: *Public health engineering*[11].

The *Solar heating: design and installation guide*[9] provides a procedure for system sizing for domestic buildings that can also be applied to commercial premises. Table 8 summarises this procedure. It is important that the storage is correctly sized to avoid excessive losses and reduce the occurrence of stagnation. The solar pre-heat storage volume required depends on the

Table 7:
Measured maximum and average daily hot water consumptions in various types of building

(Source: CIBSE Guide G[11], Table 2.11)

Building type	Total / (litres/person)	Service / (litres/person)	Catering / (litres/meal)
Dwellings	30–50	—	—
Schools and colleges — maximum — average	 13 6	 7 3	 18 6
Hotels and hostels — maximum — average	 464 137	 303 80	 62 14
Restaurants — maximum — average	 17 7	 10 3	 73 8 (4)*
Offices — maximum — average	 26 8	 10 3	 33 10
Large shops — maximum — average	 25 10	 6 4	 45 8

* 4 litre/meal is the average consumption in restaurants without large bar facilities

Note: normalised assuming 65 °C storage temperature and 10 °C cold feed temperature (except for dwellings where the assumed storage temperature is 55 °C)

Table 8:
Sizing of solar heating system for domestic buildings

(reproduced from: *Solar heating: design and installation guide*[9] by permission of the Domestic Building Services Panel)

Item	Sizing procedure
Collector	1 Calculate annual DHW load for household 2 Calculate required DHW energy and allow for system losses 3 Set a solar fraction of the total DHW energy 4 Calculate energy to be solar collected 5 Allow for orientation and shading of collector surface 6 Choose collector performance and calculate collector area
Storage	1 Calculate daily DHW load for household 2 Calculate stored DHW volume (if any) 3 Calculate dedicated solar pre-heat volume 4 Add DHW store and solar pre-heat volumes to obtain the combined store size
Heat exchanger	1 Calculate collector area 2 Set circulation rate 3 Calculate exchange area

collector area and type, but in general should not be less than 80% of the average daily demand. The temperature differential across the solar exchange coil is small, typically 6–15 °C, so storage cylinders with coils designed for use with conventional fossil-fuelled boilers will not be suitable.

Rules of thumb for sizing domestic systems are shown in the adjacent box[9].

It should be noted that the government proposes to introduce per capita consumption limit of 125 litres per day for new dwellings from 1 April 2010, which may lead to reduced hot water demand.

Rules of thumb for sizing domestic solar hot water systems

Required collector area:

- flat plate selective: 1.0–1.5 m^2 of absorber per person
- evacuated tube: 0.7–1.0 m^2 of absorber per person.

Dedicated solar storage volume:

- flat plate selective: 30–45 litres per m^2 of collector absorber
- evacuated tube: 40–60 litres per m^2 of collector absorber per person.

(Source: *Solar heating: design and installation guide*[9])

5.1.4 *How much energy can a system provide?*

As with any conventional heating system there are energy losses at each stage in the energy transfer. As well as sizing the components correctly, a well designed system needs to minimise losses from the pipework and storage vessels and parasitic losses from the circulating pump and control devices. The typical energy flow for a solar DHW system is shown in Figure 10.

The typical average annual overall useful energy output at the taps (at 55 °C) from a solar DHW system in the UK is 350–450 kW·h per m^2 of collector absorber area.

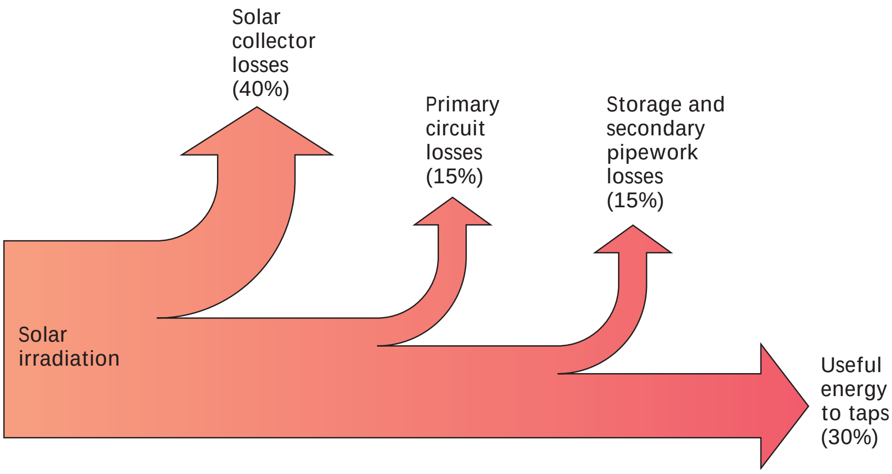


Figure 10:
Typical energy flow for a solar DHW system

(Source: *Solar heating: design and installation guide*[9])

5.2 Swimming pool heating

Swimming pool heating is an ideal application for solar energy since the peak usage, particularly for outdoor pools, coincides with the peak availability of sunshine.

For outdoor, unheated pools, solar energy can be used to raise the water temperature during the summer months and to extend the season of use. For public and commercial pools it is usually used to supplement an existing heating system.

5.2.1 *System types*

Outdoor pools

Outdoor pools use a direct (open loop) system, see Figure 11. During normal pool operation water is continuously circulated from the pool through a filter before being returned to the pool. A differential temperature controller compares the temperature at the collectors with the pool water temperature and, when sufficient solar energy is available, it diverts the filtered water through the collectors before it is returned to the pool. Some outdoor pools are heated, in which case the pool water passes through the heater before returning to the pool but the heater is only activated when the solar heating system cannot meet demand. In order to avoid problems in freezing weather conditions, the water in the collectors either automatically drains back into the pool when the flow to them is interrupted or the solar system is manually drained down at the end of the swimming season. Where heating is only required from May to September, unglazed, uninsulated collectors are likely to be most cost effective. They should be mounted in a position sheltered from the wind.

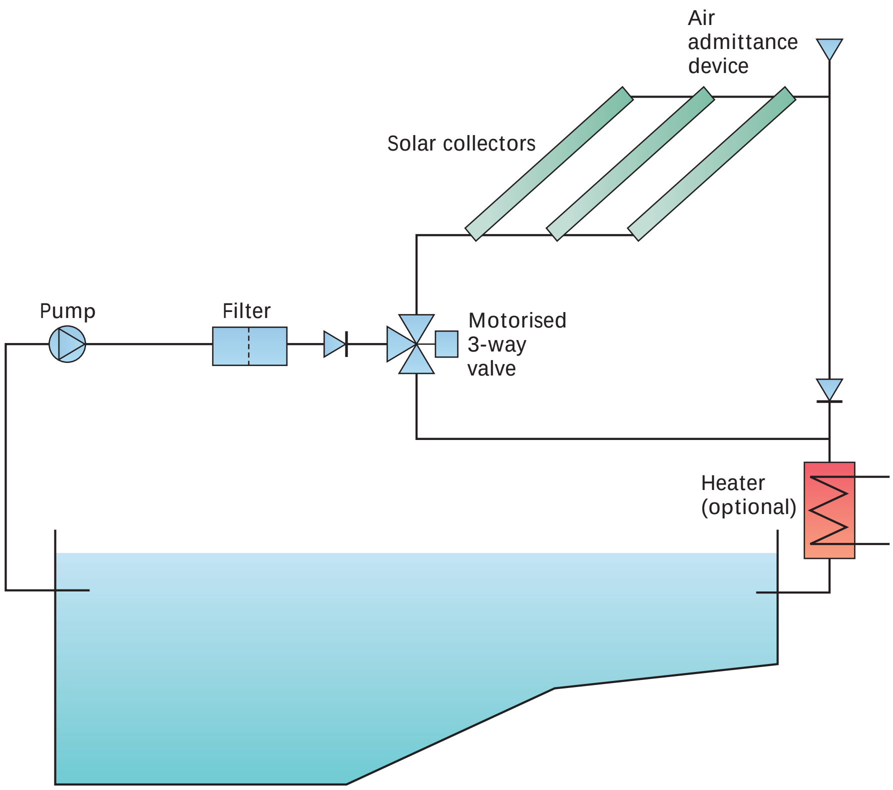


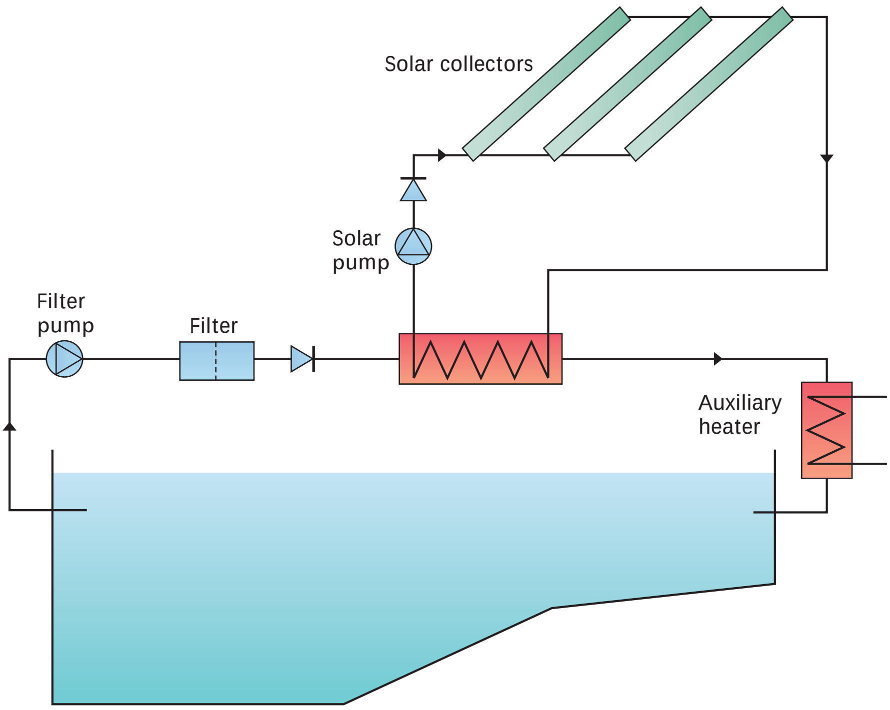
Figure 11:
Basic schematic of a direct solar water heating system for an outdoor swimming pool

Indoor pools

For indoor pools used throughout the year, an indirect system is normally used in which the filtered pool water is circulated through a heat exchanger, rather than directly through the solar collectors, before being fed to the auxiliary heater and then back into the pool. The solar collectors are connected to the primary side of the heat exchanger and the solar circuit has its own pump and is usually sealed and pressurised. A differential temperature controller compares the temperature at the collectors with the pool water temperature and when there is sufficient solar gain it activates the solar pump. Heated water from the collectors is circulated to the heat exchanger where it loses its heat to the pool water. With indirect systems, glazed and insulated collectors are usually used because of the additional temperature differential across the heat exchanger. Indoor pools are also usually maintained at a higher temperature than outdoor pools. The design issues will be similar to those for indirect solar systems for DHW heating. Figure 12 is a schematic for a typical system.

With systems of this type, any excess heat during periods of high solar gain can be used for other applications such as DHW heating.

Figure 12:
Basic schematic of an indirect solar water heating system for an indoor swimming pool



5.2.2 *System sizing*

For outdoor pools, a collector area of between 50% and 80% of the pool surface area is typically used, depending on exposure. This can provide water temperatures of about 5 °C above the average air temperature if the pool is covered at night.

For indoor pools in year-round operation, where there is auxiliary heating, the solar heating system is usually sized to provide all the heat in the month with the lowest requirement (usually July). The heating requirement of the pool will be determined by the pool size but also the desired water temperature and humidity levels. Typically, a collector area of 40% to 60% of the pool surface area is necessary with flat plate collectors and 30% to 35% with evacuated tube collectors. The area of collector may be influenced by the space available.

5.2.3 How much energy can a system provide?

For an outdoor pool with auxiliary heating, used from May to September, a solar heating system using unglazed solar collectors will typically provide between 250–350 kW·h per m^2 of collector area depending on the temperature the pool water. In addition, significant output in April can be used to pre-heat the pool providing enough energy is collected to offset the cost of running the circulating pump.

A solar heating system for an indoor pool used year-round with auxiliary heating can provide 350–450 kW·h per m^2 of absorber per year.

5.3 Air heating

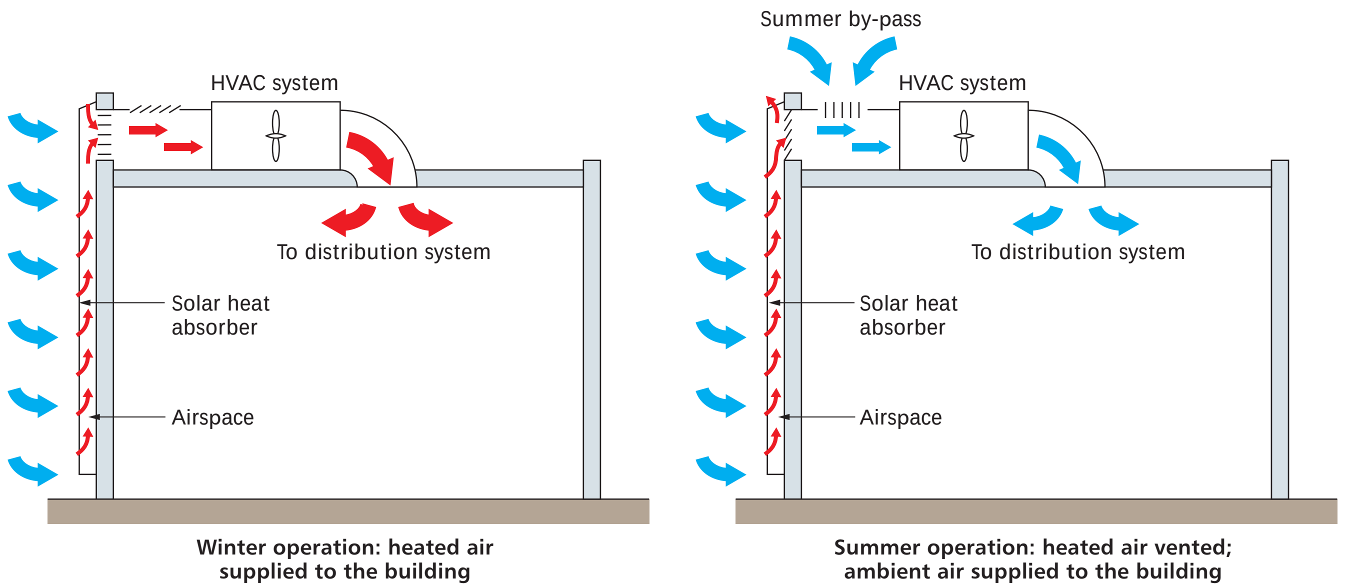
Air heating systems have some advantages over liquid-based systems. They are capable of producing heat earlier and later in the day and may therefore produce more energy over a heating season than liquid-based systems of the same size. In addition, there are no adverse effects during freezing weather conditions and minor leaks in the system do not cause serious problems, just a degradation of performance. On the other hand, as air is a less effective heat transfer medium than liquids, air-based solar collectors operate at lower efficiencies than liquid-based collectors.

5.3.1 System types

Domestic air-based heating systems usually use flat plate, glazed collectors mounted on the roof with a fan and ducting in the loft space. Space heating can be provided by circulating air from inside the building through the collectors but more commonly the collectors are used with a positive input ventilation system to pre-heat ventilation air drawn from outside or from the loft space. Typically collector output temperatures of 30 °C are possible with an input temperature of 6 °C. Output temperatures can be higher, up to 50 °C, for re-circulated air. Some systems can provide DHW heating via an air-to-water heat exchanger when space heating is not required. At night the temperature of the absorber in the collector will be below the air temperature due to radiation losses, so systems can also provide a limited amount of night-time cooling in summer.

Commercial solar air heating systems usually use unglazed perforated plate collectors mounted as an additional skin on a south facing wall or on the roof of the building with a fan and air distribution system installed on the roof or inside the building. Air is drawn through small holes in the absorber plate and is warmed as it passes over and through it. The air collects in the cavity between the solar collector and building wall and is ducted into the building. Figure 13 illustrates such a system, with the fresh, heated air being ducted

Figure 13:
Schematic of a perforated plate (transpired) air heating system



into an HVAC system where it provides pre-heating for the main heating system.

Dampers close-off the air supply from the collector if there is insufficient solar heat to raise the air to the required temperature or if there is no demand for heat. When the damper is closed, heated air from the cavity is naturally vented through the perforations at the top of the wall. In ventilation applications, bypass dampers can allow ambient air to be fed directly into the building when no heating is required. An adjustable thermostat senses the outdoor temperature and controls the dampers to switch to unheated air when the outdoor temperature is high enough to eliminate the need for heating (usually above 15–20 °C).

As the solar collector is part of the building façade, about half the heat lost through the building wall is recaptured. In summertime the solar collector shades the building wall and reduces heat gains. The solar air heating system can be connected to air handling systems used solely for ventilation, as well as to those providing space heating, cooling and ventilation, with the ventilation air making up 10–20% of the total air flow.

Solar air heating can also be used in buildings requiring large volumes of outdoor air to replace air discharged from industrial operations such as painting, welding etc. Due to the availability of wide-open areas and high ceilings, the solar heating system can replace conventional make-up air heaters. Instead of using a conventional heater to provide the additional heat required, solar make-up air heaters combine solar pre-heated air with warm ceiling air and deliver this to the building. The solar air handling unit is designed to vary the proportions of outdoor air and recirculated air to achieve a flow of constant temperature air (typically 15–18 °C).

In industrial buildings with no existing air distribution system, the interior components of the solar air heating system consist of a constant speed fan, a recirculation damper and a fabric distribution duct.

Perforated fabric ducting is a low-cost method of delivering make-up air throughout the building. A recirculation damper incorporated into the fan compartment mixes indoor air with solar collector air to maintain a constant air temperature. The ratio of indoor (recirculated) air to outdoor air heated by the solar air heating system varies continuously with changes in the solar collector outlet air temperature, while a duct thermostat operates the damper system.

The mixture of ventilation air and recirculated air is distributed to the building through perforated fabric ducts at ceiling level. Because the air from the ducting is cooler than air at the ceiling, the ventilation air will cool the ceiling, reducing heat loss through the roof and helping to destratify the building air.

5.3.2 System sizing

Domestic air heating systems using flat plate air collectors typically use a collector area of about 5 m^2. The size is not critical.

For commercial solar air heating systems using perforated plate collectors, the size of the solar collector depends on the ventilation rate required and the wall area available. The lower the volume flow through the collector the higher the temperature rise but heat losses will increase. The system is sized to provide either a large temperature rise or high solar collection efficiency. A high-efficiency design will increase the annual energy savings and possibly decrease the solar collector size, but the average air temperature rise will be reduced. Volume flows vary from 0.3 to 3.0 $m^3 \cdot h^{-1}$ per m^2 of collector with a corresponding range in temperature rise from 35 °C down to 10 °C. The velocity of the air in the cavity should be around 1.5–3 $m \cdot s^{-1}$. Higher temperatures are necessary if some space heating is required as well as heating the ventilation air, whereas high volume flows may be needed for industrial applications.

5.3.3 How much energy can a system provide?

A domestic system using flat plate air collectors to heat the air provided by a positive input ventilation system can be expected to provide 240–350 kW·h per annum for each m^2 of collector area. If the system is also used to provide heating for domestic hot water, use can be made of energy collected throughout the year and the useful annual system output will be increased to about 500 kW·h per m^2 of collector area.

Solar air heating systems using perforated plate collectors have only recently been introduced to the UK. Performance monitoring undertaken by BSRIA[(12)] show that annual outputs of 250–350 kW·h per m^2 are possible for a south facing solar wall.

5.4 Solar cooling

Thermally driven cooling machines such as absorption or adsorption chillers are normally powered by industrial waste heat or by district heating schemes, but solar energy can be used to drive such chillers. As the need for cooling applications such as air conditioning usually coincides with the availability of high levels of solar irradiation, solar energy can be used for cooling purposes, thus replacing much of the electrical power that would normally be used. Larger solar cooling systems were developed initially, but smaller machines for use in residential and small office buildings are now becoming commercially available.

Solar cooling is still not yet widely available and there are currently a number of barriers to its growth:

- There is a lack of awareness of solar cooling.
- The required skills are not generally available among professionals.
- The availability of small capacity units and of package solutions for residential and small commercial applications may be limited.
- Only low thermal efficiencies can currently be achieved and systems often require a wet cooling tower.
- There is a lack of standardised hydraulic schemes and simple design tools.
- The systems have higher initial investment costs compared with conventional cooling systems and are generally not yet cost-effective.
- Solar cooling is often ignored in today's financial incentive schemes for harnessing solar energy.

Solar cooling installations generally consist of the components used in a conventional water heating system, i.e. solar collectors, storage tank, control unit, pipes and pumps plus a thermally driven cooling machine. The solar collectors need to be a high-efficiency type, such as double-glazed, selective flat plate collectors or evacuated tube collectors. Products are still under development and there is scope for the overall efficiency of systems to improve.

5.4.1 System types

Cooling can be provided using either a closed or an open refrigerant system. Closed systems use either absorption (liquid sorbent) or adsorption (solid sorbent) chillers to provide chilled water. Solar heat is used to regenerate the sorbent by driving off the refrigerant. Systems using absorption chillers are the most common (for information on absorption cooling see Good Practice Guide GPG256: *An introduction to absorption cooling*[13]). Open systems supply cooled and dehumidified air using a desiccant cooling system and solar heat is used to remove water from the desiccant. Figure 14 is a schematic of a desiccant solar cooling system and Figure 15 illustrates the psychrometric processes involved.

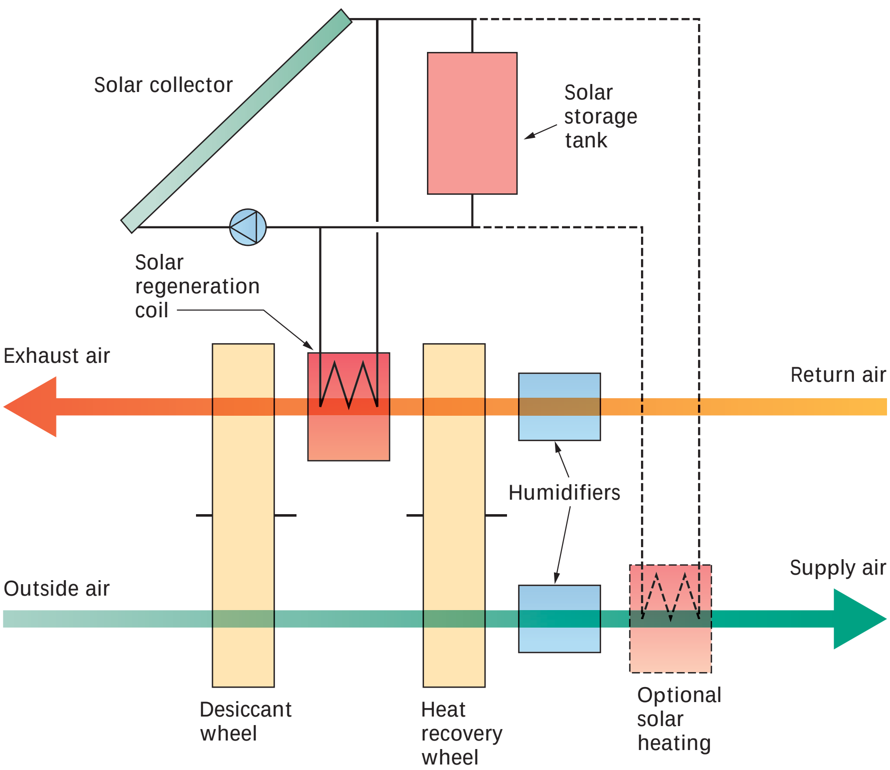


Figure 14:
Basic schematic of a desiccant solar cooling system

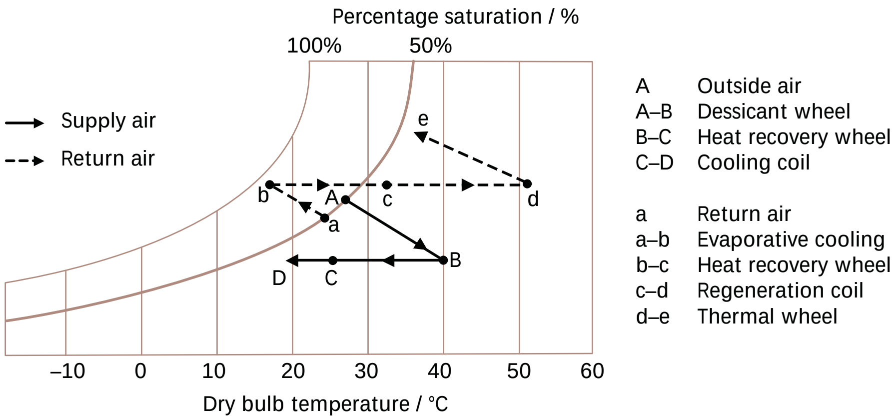


Figure 15:
Psychrometric processes for a desiccant solar cooling system

The economics of solar cooling become more favourable if the solar system also delivers energy for heating and this is shown as an option in Figure 14. In open systems the refrigerant is always water since it is in direct contact with the atmosphere. In all the above systems, careful consideration should be given to the method of dealing with the rejected heat.

The most common technologies used in combination with solar heat are summarised in Table 9.

Table 9:
Characteristics of the most common solar assisted technologies
(reproduced by kind permission of Solair)

Characteristic	Type of refrigerant cycle			
	Closed (refrigerant flows in closed cycle)		Open (refrigerant in direct contact with air)	
Principle	Chilled water		Dehumidification of air and evaporative cooling	
Phase of sorbent	Solid	Liquid	Solid	Liquid
Typical material combination (refrigerant–sorbent)	Water–silica gel	Water–water/lithium bromide Ammonia–water	Water–silica gel Water–lithium chloride	Water–calcium chloride Water–lithium chloride
Available technology	Adsorption chiller	Absorption chiller	Dessicant cooling	Not available*
Typical cooling capacity	5.5 kW to 500 kW	4.5 kW to 5 MW	20 kW to 350 kW (per module)	—
Typical coefficient of performance†	0.5 to 0.7	0.6 to 0.75 (single effect)	0.5 to >1	>1
Typical driving temperature	65 to 90 °C	80 to 110 °C	50 to 95 °C	50 to 70 °C
Solar collectors	Evacuated tube, flat plate	Evacuated tube, flat plate	Flat plate, air collectors	Flat plate, air collectors

* Technology close to market introduction
† Coefficient of performance (COP) = chilling capacity/driving heat

5.5 Electricity generation (photovoltaics)

PV systems convert solar radiation into electricity. The majority of systems are grid-connected so that any electricity generated that is excess to demand can be exported to the distribution network. Standalone systems require battery storage and will not be considered here. A typical grid-connected system contains:

- an array containing photovoltaic cells (see section 4.3) which generates a direct current (DC)
- a power conditioning unit (PCU), i.e. an inverter, that converts the DC power to an alternating current (AC) synchronised with the grid and at the correct voltage and frequency.

The system is connected to the electrical supply system of the building via the standard building wiring and the mains switchboard, and to the utility grid via import and (where appropriate) export metering, see Figure 16.

Grid-connected installations need to conform to the requirements of Engineering Recommendations G59/1[14] for installations up to 16 A per phase or G83/1[15] for larger installations. These documents were published by the Electricity Association (and now available from the Energy Networks Association), and are recognised by the UK electricity industry as best practice when considering the connection of embedded generating plant to the distribution network.

The primary concerns when considering connection of a generator in parallel with the distribution network are safety and power quality. The main safety issue is the possibility of the generator continuing to supply power to a section of the network that has lost the mains supply. Therefore the installation will require protection to ensure that the generator output is automatically disconnected from the grid if a loss of mains condition occurs. For power quality, the generator output should not result in disturbance beyond established limits.

The connection agreement is made with the host distribution network operator (DNO); this will normally be the local electricity supply company. It is important that contact is made with the DNO early in the design process

Metering options

Options for metering are:

- one-way metering: incoming supply only
- two-way metering: separate import and export meters, or a single meter incorporating both functions.

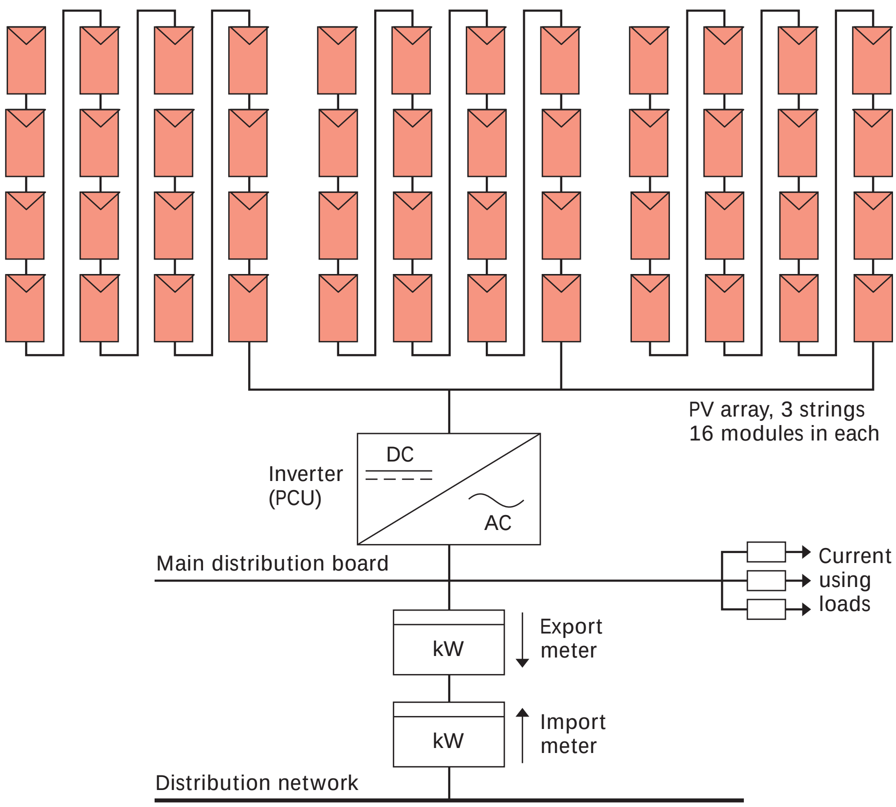


Figure 16:
Schematic of a PV installation

as this will help to ensure both that the DNO service meets the designer's requirements and that the PV installation meets the DNO's requirements. It is also important that the DNO is kept informed of any changes that are made to the PV installation during the life of the building.

5.5.1 Integrating PV into a building

PV modules are available in a wide variety of forms, e.g. framed, unframed, roof tiles or other building components, and if the cells are mounted between sheets of glass they can be semi-transparent or translucent. They can often be integrated into the building structure (known as 'building integrated PV' (BIPV)), in which case the cost of the PV system can be offset against the building element that it replaces.

PV arrays can be integrated into either the roof or façade of a building; the main systems of each type are listed in Tables 10 and 11. Roof mounting can have the highest performance and shading and vandalism are less likely to be a problem but allowance has to be made for the additional weight. Care is

Table 10:
Design considerations for facade PV systems

Facade type	Design considerations
Vertical curtain walling	Economical construction; can utilise opaque or semi-transparent PV cells or clear glazing
Inclined wall glazing	Increased energy output must be balanced against loss of useable floor space
Rain-screen cladding	PV modules usually mounted to leave a ventilation gap; suitable for retrofitting
Sun shading	PV array independent of the building weatherproofing envelope; can be fixed or moveable; can use opaque PV modules (as awnings or light shelves) or semi-transparent modules

Table 11:
Design considerations for roof mounted PV systems

Roof type	Design considerations
Inclined roof	Panels fastened to roof structure or PV roof tiles or slates
Curved roof	Opaque PV on a metal substrate; offers design flexibility
Skylights	PV system as individual roof openings; opaque or semi-transparent; many possible configurations: flat, saw tooth, etc.
Atrium	Semi-transparent PV skylights
Roof-mounted*	Panels mounted on a support structure on top of a flat roof

* In this case the PV array will not displace other building elements

also needed to avoid rain penetration. Façade mounted arrays provide more opportunities for additional use such as rain screening or sun shading and are usually highly visible so can make a clear aesthetic or environmental statement.

5.5.2 Design issues

General design issues which need to be considered include:

- shading (as discussed in section 2, minimising shading is critical for PV arrays)
- avoidance of unwanted heat gains to the building or the use of heat (using the waste heat from the PV array and possibly inverters can improve the system efficiency)
- weathertightness
- windloading
- lifetime of components and materials (where possible this should match the lifetime of the of the PV modules which is 20–30 years)
- replacement of failed or damaged modules.

To ensure the safety of a PV installation the designer must consider the potential hazards and design the PV system to minimise risks. The main safety issues are:

- The electricity supply from PV modules cannot be switched off, so special precautions are needed to ensure that live parts are not accessible or cannot be touched during installation, use and maintenance.
- PV modules require specialised over-current protection (a photovoltaic cell acts as a current source; PV modules are thus current-limiting devices so the short circuit current is very similar to the operating current and conventional fuses will not operate)
- PV systems require particular attention to over-voltage protection (earthing and lightning protection).

Design guidance for BIPV is given in CIBSE TM25: *Understanding building integrated photovoltaics*(6). For mechanical design see BRE Digest 489: *Wind loads on roof-based photovoltaic systems*(16) and BRE Digest 495: *Mechanical installation of roof-mounted photovoltaic systems*(17).

Architectural modelling software packages can provide three-dimensional modelling and visualisation of the PV system and the effects of shading. Computer-based tools are available for the detailed design of PV arrays as the way in which modules are linked will depend on building geometry and shading in addition to the effects of orientation, tilt etc.

Comparative weights for typical solar installations

Typical values for the mass per unit area for different types of solar installation are:

- PV modules: 10–13 kg/m^2
- solar collectors:
  — flat plate: 16–22 kg/m^2
  — evacuated tube: 17–25 kg/m^2

Typical sizes for PV installations

- Dwelling: 0.8–2.5 kW_p
- Primary school: 3.5 kW_p
- Secondary school: 10 kW_p
- Office: 20 kW_p

5.5.3 System sizing

Typical electricity loads for the building type (office, house etc.) and an estimate of energy output from the PV system can be used as the basis for approximately sizing a PV array.

The sizing of the array may also be influenced by a number of other factors, such as:

- the budget available for the PV installation
- the available area of facade or roof
- carbon savings required (the *Low or Zero Carbon Energy Sources: Strategic Guide*[18] provides a method to calculate the potential of PV systems to contribute towards lowering the CO_2 emissions of a building in order to comply with Part L of the Building Regulations[19]).

As PV systems are generally not directly related to a specific building element or service, sizing can be flexible.

Although it is possible to export any excess electricity generated by the system to the grid (provided that the correct metering arrangement is installed), the price paid for exported energy is usually less than the consumer purchase price. Therefore, at present, it is not recommended that the system be oversized deliberately to enable electricity to be exported. This may change in the future, with the introduction of feed-in tariffs. However, and it is worth checking with the local electricity supplier what they will pay for exported electricity.

5.5.4 How much energy can a system supply?

The annual energy output can be estimated using figures for the total annual incident solar radiation for the location, adjusted for the tilt and orientation and the actual efficiency of the array. Solar radiation data are available from a wide range of sources including CIBSE Guide A: *Environmental design*[20]. These are usually 'average' data and the actual performance of a system in any given year is likely to vary from the value calculated using such data due to the statistical variation of solar radiation.

Allowance has to be made for losses in the rest of the system in addition to those from the PV array, these are mainly losses due to the inverter (10–15%) and wiring losses (1–3%)[21]. The term 'balance of system' (BOS) is usually used for everything in the system apart from the PV array. The total balance of system loss is typically about 15%. In addition there will be losses due to temperature effects, dust, mismatch between modules etc., which together reduce the energy output by about 10%.

Output of a PV system

The annual electricity produced by the photovoltaic system is given by the following equation[22]:

$$Q_{pv} = I\, K_e\, (1 - K_s)\, A$$

where Q_{pv} is the electricity produced by the photovoltaic system (kW·h), I is the global solar radiation at the module surface (kW·h/m^2), K_e is the module efficiency of conversion (%), K_s is the system losses (%) and A is the area of the modules, excluding any supporting structure (m^2).

The CO_2 emissions displaced by the electricity generated by the photovoltaic modules are calculated by the equation:

$$C_{pv} = Q_{pv}\, C_d$$

where C_{pv} is the total CO_2 emissions displaced by the photovoltaic system (kgCO_2), C_d is the carbon emission factor for the grid electricity displaced (kgCO_2/kW·h), i.e. the amount of CO_2 displaced by each kW·h of electricity produced

Note: the carbon emission factor currently assumed for grid displaced electricity may be different from the carbon emission factor assumed for grid-supplied electricity.

The yield from a PV system can be expressed either in terms of the annual energy output per square metre of module area (kW·h/m^2·per year) or in terms of the annual energy output per peak kilowatt of 'rated' power (kW·h/kW$_p$ per year).

The following energy outputs can be used as a rough rule of thumb for the UK:

- 1 m^2 of monocrystalline or polycrystalline array will produce a useful output of 90–110 kW·h per year (assuming a reasonable tilt, orientation and system efficiency).
- 1 m^2 of amorphous silicon thin film array will produce a useful output of 30–70 kW·h per year (assuming a reasonable tilt, orientation and system efficiency).
- A roof-mounted, grid-connected system will produce approximately 700–800 kW·h per year for each kW$_p$ installed.

Figure 17 shows how the expected annual output varies with tilt and orientation of the PV modules.

The annual CO_2 savings would be about 0.43 tonnesCO_2/kW$_p$ based on an emission factor for the electricity displaced of 0.568 kgCO_2/kW·h (see Building Regulations Approved Document L2A[23]).

Factors affecting the annual energy output of PV systems

- The amount of solar radiation available at the site
- The orientation and tilt of PV arrays
- The peak power rating of the arrays (array area)
- The energy conversion efficiency of the modules
- How the efficiency of the modules varies with the spectral distribution of the solar radiation
- The efficiency of the inverter
- The transmission losses

Tilt	Annual output as percentage of maximum for stated orientation (with respect to due south) and tilt / %												
	–90° West	–75°	–60°	–45° SW	–30°	–15°	0° South	15°	30°	45° SE	60°	75°	90° East
Vertical	56	60	64	67	69	71	71	71	71	69	65	62	58
80°	63	68	72	75	77	79	80	80	79	77	74	69	65
70°	69	74	78	82	85	86	87	87	86	84	80	76	70
60°	74	79	84	87	90	91	93	93	92	89	86	81	76
50°	78	84	88	92	95	96	97	97	96	93	89	85	80
40°	82	86	90	95	97	99	100	99	98	96	92	88	84
30°	86	89	93	96	97	99	100	100	98	96	94	90	86
20°	87	90	93	96	97	98	98	98	97	96	94	91	88
10°	89	91	92	94	97	95	96	95	95	94	93	91	90
Horizontal	90	90	90	90	90	90	90	90	90	90	90	90	90

Figure 17:
Chart showing annual output available from a PV system as a percentage of the maximum

6 Installing solar thermal and photovoltaic systems

No unusual construction practices are involved in the installation of either solar thermal or solar PV systems but, especially for PV, unusual combinations of skills may be required that may be unfamiliar to conventional construction teams. The use of installers certified by the Microgeneration Certification Scheme[24] is recommended. This section considers some of the key installation issues.

6.1 Health and safety

The design should aim to minimise the risks that installers are exposed to and relevant health and safety legislation must be adhered to. Installing solar thermal collectors or PV arrays can present risks from the following:

- *Working at height*: specialised access equipment, e.g. scaffolds, hoists etc., is often required.
- *Handling*: solar collectors and PV modules are bulky and relatively heavy and PV laminates may require specialist glass handling techniques.
- *Burns or scalding*: solar collectors exposed to the sun can reach temperatures in excess of 200 °C and even PV modules can reach 90 °C. Pipework for solar thermal collectors may require high temperature brazing as soft solder cannot withstand the high stagnation temperatures. There is a high risk of scalding when the primary circuit is initially tested if the absorber is hot, as the water will flash to steam as the collector is filled. Where possible collectors should be covered to stop solar radiation reaching the absorber until initial testing of the primary circuit is completed.
- *Electric shock*: PV modules generate electricity whenever they are exposed to daylight and individual modules cannot be switched off so, unlike most other electrical installations, installing a PV system involves working on a live system. Again, covers can be used to stop solar radiation reaching the PV cells but this is not always practicable.

Solar installations present a unique combination of hazards due to the risk of electric shock and/or burns, falling and simultaneous handling difficulties.

6.2 Materials management

Components, especially solar collectors and PV modules, are valuable and to minimise the possibility of accidental damage, vandalism or theft it is best to arrange for system components to be delivered at the appropriate time in the construction schedule.

If components need to be stored on site they should be securely stored out of sunlight. Evacuated tube collectors are particularly vulnerable to damage as even small scratches can seriously weaken them.

6.3 Scheduling

Timing of the installation may be critical to avoid construction delays especially if the collectors or PV arrays form part of the weathertight enclosure of the building.

For PV installations all DC wiring should be completed prior to installing the PV array where possible. This will allow effective isolation of the DC system while the array is installed and effective isolation of the PV array while the inverter is installed.

7 Commissioning and maintenance

7.1 Commissioning

Commissioning is a requirement of the Building Regulations[19]. Systems should be commissioned according to a documented procedure to ensure that they are safe, have been installed in accordance with the manufacturer's requirements and are operating correctly and in accordance with the system design. Commissioning must be carried out by competent personnel (for the required competencies see Department for Energy and Climate Change standards MIS 3001[25] for solar water heating and MIS 3002[26] for PV).

7.1.1 Solar thermal systems

A solar thermal system should be commissioned on a bright or sunny day with the collector temporarily covered, and the primary system and dedicated solar storage both cool. Circuits should be thoroughly flushed before being filled and, where possible, de-oxygenated and de-ionised fluid should be used in the primary circuit to avoid oxygen boiling-out when the fluid is heated. The temporary covers should only be removed once circulation has been established and all safety controls are operating correctly. The system can then be allowed to heat-up and the controls, such as the differential controller, can be set.

7.1.2 Photovoltaic systems

PV systems should be tested and commissioned in accordance with BS 7671[27]. The inspection and testing of DC circuits requires special considerations (for information see appendix C of DTI guide *Photovoltaics in buildings: Guide to the installation of PV systems*[28]. It is important to test for any faulty modules. For grid-connected installations specific tests and documentation will be required by the DNO which normally cover synchronisation with the grid, safety interlocks (to disconnect the PV supply if the mains supply fails) and adequate provision of warning labels. Allowance may need to be made for witness testing by the DNO and for poor weather conditions.

7.2 Maintenance

Documentation for the installed system should include a maintenance schedule and the competency requirements for inspection and maintenance. A log of all maintenance should be maintained.

7.2.1 Solar thermal systems

Water-based solar systems for DHW, swimming pool heating, space heating and space cooling have similar maintenance requirements. Most systems will benefit from annual inspection checks. A list of visual checks could include the following:

- check the collector (for damage to glazing or the absorber and build-up of dirt)
- check fixings are sound and that there are no signs of water penetration
- check the pipework (for physical damage, signs of leaks and that insulation is in place)
- check fluid and/or pressure levels
- check that the pump and any valves are operating correctly
- check controls and temperature sensors are operating sensibly
- check all safety and information labels are in place.

Maintenance to ensure the correct operation of critical safety devices and to check for degradation of antifreeze (if used) should be carried out at least every 5 years. Regular de-scaling of the secondary side of the heat exchanger in a solar store may also be needed in hard water areas.

In general, air-based systems require less maintenance than water-based systems. Similar checks on the collector (for glazed collectors) and fixings will be needed but small air leaks from ducting will not be critical. Maintenance may include checking and replacement of air filters and the operation of the fan and dampers. Perforated air collectors will require very little maintenance.

7.2.2 Photovoltaic systems

It is important to ensure that workers are aware of the special features of the PV system and are familiar with the potential hazards and necessary safety procedures. All warning and information labels should be carefully maintained.

A well-designed PV system will require very little maintenance. Problems within modules are unlikely as they have no moving parts and balance of system (BOS) components (i.e. those other than the PV array itself) should be chosen for high reliability. However, a PV generator has a large number of interconnections, possibly exposed to the external environment over the lifetime of the PV modules, which is at least 20 years. Therefore electrical faults are likely to occur in the interconnections between the modules and in the BOS unless the installation is regularly checked, inspected and tested.

If the PV array is installed at an angle of more than 15° to the horizontal it is likely to be adequately cleaned by rainfall in normal circumstances. Cleaning the array once a year, however, can improve the appearance and this will be important for prestige buildings. If cleaning is necessary (in industrial areas or near busy roads) cleaning agents which might damage seals or contacts should be avoided.

Approximately twice a year the following, mainly visual, checks should be carried out taking particular care to look for signs of electrical faults:

- check PV modules for cracked glazing and cells, delamination, moisture ingress etc.
- check the DC wiring and connections for signs of arcing, corrosion, damage or degradation.

A monitoring system should pick up any problems with the array but it may be necessary to check the power output of individual array strings to locate a suspected fault.

8 Costs and benefits

There are few maintenance and running costs for either solar thermal or PV systems, although an alternative source of heat and/or electricity is generally required, with the associated costs, whichever system is chosen.

8.1 Domestic system costs

The capital costs for typical domestic solar thermal and photovoltaic systems (based on a three bedroom semi-detached house) are given in Table 12. A domestic PV installation is typically between 1.5 and 3 kW_p but the size is often determined by the space available for the array or the budget.

Table 12: **Installed costs for typical domestic solar thermal and photovoltaic systems**

System type	Typical size / m^2	Useful energy / (kW·h/year)	Carbon saving / (tCO_2/year)	Installed cost / £
Solar DHW	3 to 4[1]	1000 to 1500	0.3[2]	3000 to 5000
Solar air heating[3]:				
— ventilation air only	5	1400 to 1800	0.4[2]	5000
— ventilation air + DHW	5	2500 to 2800	0.6[2]	7000
Photovoltaic (per kW_p)	10 to 20[4]	750	0.4	5000 to 7500

Notes:
[1] The area using evacuated tube collectors will be smaller than for flat plate collectors, but the cost will be higher.
[2] Savings are from displacing gas heating.
[3] Using flat plate air collectors
[4] Array area depends on the type of photovoltaic cells

8.2 Non-domestic system costs

8.2.1 Domestic hot water

The costs for non-domestic solar DHW installations will be similar to those for domestic installations but for larger systems there will be some economies of scale, mainly due to reduced losses as the heat can be stored in larger units. Operating costs will depend on the complexity of the system. For larger systems approximately 1 kW·h of electrical energy will be required to generate 40–50 kW·h of heat. Maintenance costs are approximately 1–1.5% of the investment cost.

8.2.2 Swimming pool heating

The costs for swimming pool heating can be lower than for DHW heating depending on the type of collector used. Simple solar unglazed collectors either as solar matting or framed collectors are usually used for outdoor pools but glazed flat plate or evacuated tube collectors are often specified for indoor pools. Collector costs range from approximately £50/m^2 (of collector area) for simple solar matting to £150/m^2 for unglazed framed collectors and up to £350/m^2 for evacuated tube collectors.

8.2.3 Air heating

For commercial buildings, pre-heating ventilation air is usually carried out using perforated plate collectors. Although this technology is well established in Canada it has only recently been introduced in the UK. The installed cost of a perforated plate collector is about £50/m^2. The system is used to pre-heat ventilation air so the additional costs for the air handling system are minimal. The area of collector required will depend on the air volume and temperature rise required. The collector is installed as an additional surface layer, so any cost savings from displacing other cladding materials are likely to be small. Where the supplied air provides de-stratification there may be additional cost benefits.

8.2.4 Solar cooling

Solar cooling is also a relatively new technology. Systems are available commercially but volume sales are small and therefore capital costs are high. The costs for the solar collector system will be similar to those for a solar heating system for domestic hot water using high efficiency collectors. A recent study of solar cooling installations across Europe[29] found that total system costs for absorption cooling were about £5000/kW cooling for a 70 kW cooling system and a 210 m^2 flat plate solar collector, reducing to about £2700/kW cooling for a 460 kW cooling system and a 1400 m^2 flat plate solar collector. For smaller systems the solar collector is approximately 20% of the total cost and the thermal chiller about 15%. For larger systems the solar collectors form a larger proportion (up to 40%) of the total cost; the chiller cost is less significant at about 10%. Capital costs are from 3.5 times (for smaller systems) up to 7.5 times higher than for conventional cooling systems using electrically driven vapour compression chillers.

The capital costs for systems using adsorption chillers are higher than for absorption systems, as the technology is less well developed.

For solar cooling systems using desiccant technology the costs depend on the air change rate required and range from about £18 to £25 per m^3/h. The unit cost decreases as the capacity of the system increases, with the solar collectors accounting for between 30% and 40% of the total cost and the desiccant cooling system between 15% and 20%. The capital costs for solar assisted desiccant cooling systems are between 100% and 150% higher than for conventional cooling systems. Annual maintenance costs are typically 1–1.5% of the installed cost.

At present the running cost savings are unlikely to offset the increased capital costs for systems using thermal chillers, but solar assisted air conditioning using desiccant cooling may have an economic advantage where the solar collectors can also be used to provide heat. As solar cooling technologies become more established capital costs are likely to fall. The cost of electricity may also be an argument as a thermally powered cooling process requires only a quarter (for absorption/absorption chiller-based systems) or a half (for desiccant-based systems) of the electrical power required by a conventional cooling system.

8.2.5 Photovoltaics

For commercial PV installations (>10 kW_p) the 'turnkey' price will depend on the type of technology used and degree of integration and ranges from £4600/kW_p to £8900/kW_p. The average price in 2007 was £6300/kW_p (57% of this was for the PV array) and had fallen by approximately 10% since 2000; prices are expected to fall further[30]. Frequently part of the cost can be offset due to the displacement of conventional cladding materials. Typical module costs are £450/m^2 for mono-crystalline, £375/m^2 for polycrystalline and £160/m^2 for tandem junction thin film amorphous silicon.

8.3 Payback times

8.3.1 Economic payback

The simple economic payback times (the time in years taken for the cost savings to offset the initial capital cost) for some swimming pool heating systems and air source heating systems can be under 10 years but, in general, the payback times for photovoltaic and solar thermal systems are long and may be longer than the lifetime of the system. However, these estimates do not include potential fuel price increases and any grants or other incentives that could reduce the payback times substantially. The installation of a solar system may also increase the value of a building.

8.3.2 Energy payback

The energy payback time (the time needed in years for a system to reimburse its energy content) is between 2 and 4 years for solar thermal systems and between 3 and 5 years for photovoltaic systems, depending on location and whether it is roof or façade mounted.

Non-financial benefits

- Generates clean, inflation-proof heat/electricity
- Reduces CO_2 emissions
- Meets corporate social responsibility (CSR) requirements

8.3.3 Carbon payback

The carbon payback (the time needed in years for a system to offset its carbon content by carbon savings) for solar thermal systems is about 2 years and for photovoltaic systems between 4 and 6 years, depending on the technology used.

8.4 Other economic considerations

A number of financial incentives are available for both domestic and commercial installations. The types of measure and a brief description are given in Table 13. The Government has been, and currently (May 2009) is, providing capital grants for householders and non-profit making organisations but as the nature of such grants changes details of specific schemes have not been included.

Table 13:
Financial incentives that can encourage the use of solar technologies

Measure	Technology covered	Description
Capital grants	Solar thermal and PV	Possible sources include government programmes, local authorities and utilities; for information see the Energy Saving Trust[31] and the Renewable Energy Centre[32]
VAT	Solar thermal and PV	Reduced VAT at 5% for professional installations.
Enhanced capital allowances[33]	Solar thermal	Companies can claim 100% capital allowance in the year of purchase for products that meet minimum performance requirements.
Loans	Solar thermal	Interest free, unsecured loans of up to £200,000 (£400,000 in Northern Ireland) for the purchase of renewable energy equipment are available to small and medium sized companies from the Carbon Trust[34].
Renewable Obligation Certificates (ROCs)	PV	The Renewables Obligation[35] places an obligation on suppliers of electricity to source an increasing proportion of their electricity from renewable sources and Renewable Obligation Certificates (ROCs) are issued to generators, which can then be sold to suppliers. Smaller PV systems (<50 kW_p) receive one ROC for every 0.5 MW·h generated and larger systems one ROC for every MW·h, subject to having suitable metering. One ROC is worth £30 to £40 (about 3 p per kW·h generated) and can be sold to utilities or on the open market.
Levy Exemption Certificates (LEC)	PV	For each MW·h that an accredited renewable generator produces, OFGEM* issues a Levy Exemption Certificate (LEC). Each certificate has a nominal value (for the amount of Climate Change Levy from which they secure exemption) which, as of 1/04/2009, was £4.70. They can be sold to utilities.
Feed-in tariffs (proposed)	PV	The Energy Act 2008[36] provides enabling powers for the introduction of feed-in tariffs, which it is proposed will replace the Renewables Obligation as a support mechanism to encourage small-scale electricity generation (up to 5 MW capacity) from April 2010. Feed-in tariffs will guarantee a price for a fixed period, which will reduce the payback period and increase the return on investment.
Renewable Heat Incentive (RHI) (proposed)	Solar thermal	The Energy Act also allows for the setting up of a Renewable Heat Incentive (RHI) which it is proposed will provide financial assistance to generators of renewable heat including solar thermal systems from April 2011.

* Office of the Gas and Electricity Markets (http://www.ofgem.gov.uk)

9 Legislation, regulations, and planning policy

There are no specific policies requiring the installation of solar thermal or solar photovoltaic systems. However there is an increasing amount of legislation which promotes their use in buildings. The key driver is that the use of solar thermal and photovoltaic systems can help to reduce carbon emissions. The Climate Change Act 2008[37] enshrined in law the UK's ambitious target to reduce carbon emissions by 34% (relative to 1990 levels) by 2020 and 80% by 2050. The UK also has a legal obligation under the EU Renewables Directive[38] to meet 15% of its energy supply from renewable energy by 2020.

Legislation applicable to solar energy systems is summarized in Table 14. Recent planning reforms have urged planners to take into consideration the need to develop more renewable energy in their regions and Planning Policy Statement PPS 22[40] provides a framework for understanding how planning permission can be granted. A growing number of local authorities are requiring integrated renewable energy systems to be specified on new developments under revisions to their local plans. In England and Wales the Town and Country Planning (General Permitted Development) Order 1995[41] allows most domestic solar installations to proceed without planning permission, provided they meet certain size requirements and the building is not listed or in a designated area.

The Building Regulations[19] set legal minimum standards. Specific guidance on the use of solar technologies is given in the *Domestic Heating Compliance Guide*[45] which is a second tier document supporting Part L of the Building Regulations (the proposed *Domestic* and *Non Domestic Building Services Compliance Guides*[46,47] for the 2010 revision of Part L also contain guidance on photovoltaics). The Microgeneration Certification Scheme[24] has also been introduced to provide independent certification of solar products and services which helps to improve the protection for consumers.

The use of solar energy systems can help to improve the rating achieved by a building for environmental and energy performance assessment schemes such as BREEAM[42] and the Code for Sustainable Homes[43] and for Energy Performance Certificates[44]. Further information is available in CIBSE's *Energy and carbon emissions regulations*[48]. The target set by Government for the building industry is that by 2016 all new-build housing will be net zero carbon and all new-build commercial properties net zero carbon by 2019.

Table 14:
Legislation relevant to solar energy systems

Legislation/guidance	Key aspects relating to solar thermal and photovoltaic systems
Planning Policy Statement PPS 1: *Delivering sustainable development* (England and Wales)[39]	Legislation to deliver sustainable development that seeks to promote the use of small-scale renewable energy. The 2007 supplement expects local authorities to require a proportion of the energy supply of new development to be from renewable sources.
Planning Policy Statement PPS 22: *Renewable energy* (England and Wales)[40]	Legislation requiring local development policies to promote and encourage the development of renewable energy sources.
Town and County Planning (General Permitted Development Order)[41]	Allows many micro-renewable installations on domestic properties in England to proceed without the need for planning permission.
Area development frameworks	Used by planning authorities to set supplementary planning guidance.
Supplementary planning guidance	A number of boroughs have potentially relevant supplementary planning guidance on maximising renewable energy generation and integration of renewable energy technologies. Many set a requirement for a specific proportion of energy consumption or reduction in CO_2 emissions through on-site renewables.
The Pressure Equipment Regulations 1999 (PED)[8]	Applies where equipment could hold pressures in excess of 0.5 bar above atmospheric under any foreseeable circumstances.
The Building Regulations 2000[19] (as amended)	Part L applies to the conservation of heat and power and sets minimum energy performance requirements in the form of target CO_2 emissions. For non-domestic buildings the target emissions rate includes a benchmark provision for low or zero carbon energy sources. Guidance on the use of solar technologies is given in the *Domestic Heating Compliance Guide*[45] and the *Low or Zero Carbon Energy Sources: Strategic Guide*[18]. Part G3 applies to unvented water storage*. Part P applies to any electrical work, including photovoltaic power.
BRE Environmental Assessment Method (BREEAM)[42]	A BREEAM rating can be improved by the use of solar systems.
Code for Sustainable Homes[43]	Level 3 and above is unlikely to be achieved without the use of renewable energy technologies.
Energy Performance of Buildings (Certificates and Inspections) (England and Wales) Regulations 2007[44]	Solar technologies can contribute to a higher rating for Energy Performance Certificates (EPCs). Further information is available in CIBSE's *Energy and carbon emissions regulations*[48].

* At the time of publication, Building Regulations Part G is under review. A draft Approved Document is available from the Department for Communities and Local Government. The proposals for amendments are available at http://www.communities.gov.uk/publications/planningandbuilding/partgconsultation

Note: planning policy is a devolved responsibility. The information given above applies specifically to England; the information on Building Regulations applies to England and Wales.

References

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2 *Design for improved solar shading control* CIBSE TM37 (London: Chartered Institution of Building Services Engineers) (2006)

3 *Heating, ventilating, air conditioning and refrigeration* CIBSE Guide B (London: Chartered Institution of Building Services Engineers) (2006)

4 *Natural ventilation in non-domestic buildings* CIBSE AM10 (London: Chartered Institution of Building Services Engineers) (2005)

5 BS EN 12975: *Thermal solar systems and components. Solar collectors*: Part 1: 2006: *General requirements*; Part 2: 2006: *Test methods* (London: British Standards Institution) (2006)

6 *Understanding building integrated photovoltaics* CIBSE TM25 (London: Chartered Institution of Building Services Engineers) (2000)

7 BS EN 12976: *Thermal solar systems and components. Factory made systems*: Part 1: 2006: *General requirements* (London: British Standards Institution) (2006)

8 The Pressure Equipment Regulations 1999 Statutory Instruments 1999 No. 2001 (London: The Stationery Office) (1999)

9 *Solar heating: design and installation guide* (London: Domestic Building Services Panel/CIBSE) (2007)

10 *The control of legionella bacteria in water systems. Approved Code of Practice and guidance* HSE L8 (Sudbury: HSE Books) (2000) (available at http://www.hse.gov.uk/pubns/books/l8.htm) (accessed August 2009)

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13 *An introduction to absorption cooling* Good Practice Guide GPG256 (Carbon Trust) (1999) (available at http://www.carbontrust.co.uk/publications) (accessed August 2009)

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