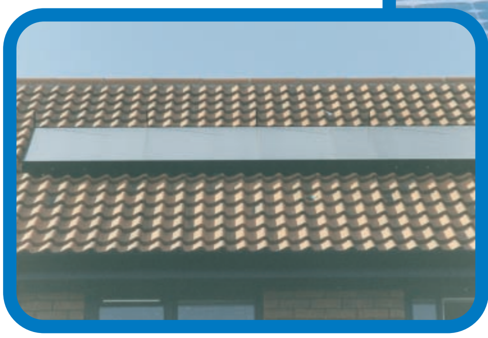



Energy Efficiency Best Practice in Housing

Renewable energy sources for homes in urban environments

- This guide offers constructive and informative advice about the opportunities and options for specifying renewable energy technologies when designing or refurbishing urban housing
- It highlights the importance and benefits of combining all appropriate measures for increasing energy efficiency before specifying and installing renewable energy sources





ENERGY EFFICIENCY™
SAVE ENERGY MONEY ENVIRONMENT

Introduction

The purpose of this guide is to give architects and specifiers clear and concise information about the integration of renewable energy sources into new and existing dwellings in urban environments.

It covers the basic principles, benefits, limitations, costs and suitability of various technologies. It will help those without a detailed technical awareness of the subject to understand what is involved when specifying or designing dwellings.

What is renewable energy?
Renewable sources of energy are those which are continuously available in our environment.

Renewable Energy:
"Energy flows derived from natural forces that are continuously at work in the earth's environment, and which are not depleted by being used"

Most renewable energy sources are derived from solar radiation. These include the direct use of solar energy for electricity generation or heating. There are indirect forms too, such as energy from the wind, waves, the flow of water and from plants and animals (i.e. straw, wood, dung etc). Other energy sources such as geothermal, tidal and energy from waste are also considered to be renewable, although the energy generated comes from sources other than solar radiation.

Why should we use it?
All over the world - and in particular the developed nations - we are consuming energy in ever increasing quantities. We use energy in every aspect of daily life from providing warmth and light, to transportation for work and pleasure.

To generate these vast amounts of energy we have until now depended largely on burning fossil fuels – primarily coal, oil and gas.

The bad news is that these are finite resources which have taken millions of years to form. Furthermore, they also release large amounts of carbon dioxide (CO_2) into the atmosphere when burnt to provide energy.

In contrast, renewable energy sources either emit no greenhouse gases, or they are carbon neutral over their life-cycle (e.g. crops used as biomass fuel only emit the same amount of CO_2 as they absorb when growing).

Using renewables can help the environment by reducing our reliance on fossil fuels, adding to the diversity and security of future energy supply, cutting energy imports and contributing to national and international targets on emissions reduction.

Commitment to global climate control
The Kyoto Protocol obligates the UK to reduce its greenhouse gas emissions to 12.5% below 1990 levels by 2008/2012. The UK has taken this further and said that it will voluntarily reduce CO_2 emissions to 20% below the 1990 level by 2010.

In setting out its strategy, the Government released the Energy White Paper in February 2003, which proposed cutting emissions further still with the aim of achieving a 60% reduction in CO_2 emissions (below the 1990 level) by 2050.

Key to this will be the increased use of renewable energy. Under the EU Renewables Directive[1] the UK has already been set a target of achieving 10% of total electricity generation from renewable energy sources by the year 2010. There is also an aspirational target to double the renewables share of electricity generation to 20% by 2020.

The Renewables Obligation
The Renewables Obligation[2] is one of the principle drivers in meeting these targets, and is scheduled to run until 2027.

The Obligation was introduced in April 2002, after an extended period of consultation with industry, consumers and others. It calls on all licensed electricity suppliers in England & Wales to supply a specified and growing proportion of their sales from a variety of eligible renewable sources.

To reach the 10% target, assessments of the renewable energy resources available in England have been carried out for the Department of Trade and Industry (DTI). Based on these assessments, individual regions have been instructed to set their own targets, which should be revised upwards if met.

The Obligation is enforced by an order (Statutory Instrument) made under the terms of the Utilities Act 2000. The Renewables Obligation Scotland[3] is the equivalent instrument in Scotland. In Northern Ireland a similar Renewables Obligation framework has been proposed.[4]

Energy efficiency before renewable energy
Heating and hot water systems consume far more energy than other household appliances; they represent the largest proportion of carbon emissions from domestic energy consumption (see Figure 1).

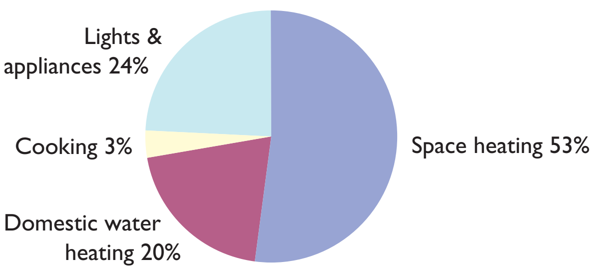


Figure 1: Carbon emissions of the UK housing stock in 2001 by energy end use (Source: Domestic Energy Fact File 2001)

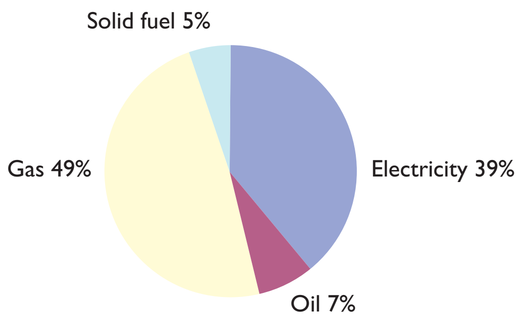


Figure 2: Carbon emissions of the UK housing stock in 2001 by fuel type (Source: Domestic Energy Fact File 2001)

Gas and electricity account for 88% of carbon emissions from fuel use in the home (see Figure 2). Much of the existing stock is of a poor standard, so there is significant scope for savings in the future.

In new and existing housing, the total energy requirement (for space heating, hot water and electricity) should always be reduced as much as possible by using appropriate energy efficiency measures, low energy design and passive solar design techniques. You can find useful Best Practice recommendations for improving energy efficiency in publications produced by Energy Efficiency Best Practice in Housing. (See Further Reading for more details.)

By achieving reduced electrical and heating demand of a dwelling, the energy requirement can be met by a smaller and cheaper renewable energy system.

Low energy design

Insulation
New dwellings need to comply with the thermal performance standards set out in the relevant building regulations. However, in the case of existing housing, standards of insulation can be improved through simple, cheap, quick and effective measures such as topping up loft insulation; or where appropriate, retrofitting cavity wall insulation.

These measures should last for the lifetime of the building. They require no maintenance or adjustment to generate energy savings. Therefore they will help reduce the requirement for top-up energy from non-renewable sources, and reduce the installed capacity and cost of renewable systems.

Other measures that might be considered include fitting external wall or floor insulation, although the costs involved are likely to be significantly higher.

Insulation should, wherever practical, be distributed around the exposed elements of a dwelling. This helps to minimise overall heat loss and thermal bridging (which can lead to condensation problems).

Heating
Heating systems must be sized correctly for the actual heat loss from the dwelling (with allowance for warm-up). Oversizing is likely to waste energy, whilst undersizing will not achieve the desired temperature. Heating controls must be able to respond to incidental and solar gains and provide adequate heating to all parts of the dwelling (21°C in living room, 18°C in the rest of the house).

Ventilation
Air infiltration through the building fabric should be minimised. Ventilation should be adequate, and through purpose-designed controllable openings such as trickle ventilators and extractor fans.

For guidance on recommendations for improving energy efficiency in new and existing housing, refer to the Summary of Specifications for England, Wales and Scotland published by Energy Efficiency Best Practice in Housing. A sister publication exists for Northern Ireland. (See Further Reading for details.)

Passive solar design
Passive solar design is a useful source of energy for dwellings. It can increase energy performance by reducing the need for heating. Further reading on this subject can be found in the information section at the back of this guide.

Key considerations:
New dwellings should, wherever possible, be positioned to take maximum advantage of solar gains, daylight and any existing protection from the wind.

To maximise passive solar gain the dwellings should be planned internally so that main living areas are facing south.

In addition:

- Space dwellings at least twice their height apart (north to south)
- Orientate houses so that their main glazed elevation faces within 30° of south
- Arrange dwellings so that main living areas and bedrooms are within 45° of south
- Avoid over-shading within 30° of south
- Use garages to shelter north elevations
- Increase the proportion of the total glazed area that is south facing
- Avoid large ventilated entrances and stairs in block of flats – they introduce a cold area into the middle of the block
- Specify heating systems and controls which respond to solar gain. Rooms subject to high solar gain should have their own zone temperature control (e.g. thermostatic radiator valves or TRV's)

Solar energy

Background

As the earth orbits around the sun, it continually receives vast amounts of solar radiation. This can be converted directly or indirectly into useful energy for dwellings.

This solar energy is equivalent to 160 times the energy stored in the world's proven reserves of fossil fuels. It is over 15,000 times greater than the world's combined annual use of fossil fuels, nuclear fuels and hydro power.

The amount of solar energy received at the earth's surface is highly variable. Influences include the atmosphere, cloud cover and the earth's rotation. In the UK we can expect to receive approximately 1000kWh/m^2 of solar radiation every year.

The level of energy in solar radiation is low compared to conventional fossil fuels, and therefore expensive to capture and harness. However solar energy is free and does not create direct CO_2 emissions.

Solar electric (Photovoltaics)

Basic principles

The term photovoltaic (PV) means the generation of electricity from light. It is derived from the Ancient Greek word for light 'photos', and 'volt' which is the term for electromotive force. Photovoltaic cells convert energy from the sun into electricity through semi-conductor cells.

The electricity is generated in the form of direct current (DC) which can either be used directly depending on the application, or converted into alternating current (AC) for household use or for exporting to the local electricity network/national grid.

The brighter the sunlight, the more power is produced - although PV cells still produce a reduced level of power when the sun is hidden by clouds. Shading from other objects (such as nearby buildings and trees) is a key issue, as PV cells are more likely to show a drop in system output than solar thermal panels. Ideally panels should face as close to due south as possible, and be unshaded for most of the day.

Because individual PV cells only provide a small amount of electricity, they are generally grouped together into a module for convenience. A full domestic system may well have several modules, together with other system components such as an AC/DC inverter, batteries (for storing the energy until it is needed), a central control unit, mounting structure or materials for fixing the array, wiring, fuses and isolator.

Producing electricity from light

A PV cell consists of a junction between two thin layers of dissimilar semiconducting materials. These materials are usually based on silicon, although PV cells can also be made from other materials. Two thin layers of silicon are treated with small amounts of chemical substances to give the PV cell its special properties and allow it to produce electricity.

The first layer, known as the 'p' type layer, is created by doping the silicon with tiny amounts of boron. This causes a shortage of electrons and hence a positive charge. The second layer is known as the 'n' type layer and, like the 'p' type, is doped with small amounts of an impurity – in this case phosphorus. This creates a surplus of electrons and hence a negative charge.

The barrier between these two layers is known as the p-n junction. When energy in the form of light is applied at this point, the electrons are given enough energy to move across the junction. This in turn creates an energy variation, otherwise known as a 'potential difference' or 'voltage'.

If a circuit is made, this potential difference drives the flow of electrons around the circuit, and an electrical current is produced.

Types of Photovoltaic cell

Different semiconductor materials are used to produce photovoltaic cells. A semiconducting material is one which only conducts electricity under certain conditions, e.g. when sunlight falls on it. The most widely used material is silicon. Silicon is one of the most abundant non-metallic elements on earth. It is used extensively in the manufacture of components for televisions, radios and computers, and is consequently much cheaper than other potential PV cell materials.

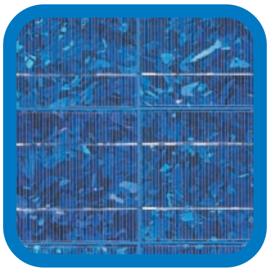
Monocrystalline

Monocrystalline silicon is usually grown from a small seed crystal that is slowly withdrawn from a molten mass of polycrystalline silicon. It is then cut into very thin wafers. All the atoms within the crystal are arranged in an orderly pattern. Once cut, the wafers can then be 'doped' with impurities to produce a cell which will convert sunlight into electricity. Monocrystalline silicon PV modules are more efficient than polycrystalline, but more expensive due to the manufacturing process which is both time and energy intensive.

Courtesy of Solar Century

Polycrystalline

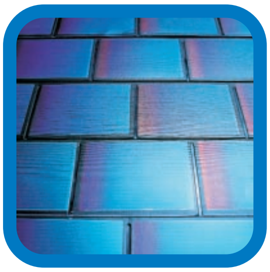
Similar to monocrystalline but instead of one single crystal, several different crystals are used. This process produces cheaper PV cells than monocrystalline, but with slightly lower efficiencies.



Courtesy of Solar Century

Amorphous silicon

In this process, silicon is made into a thin, continuous strip of material or film. Cells can be produced more quickly and cheaply than mono or polycrystalline, but efficiencies will be between three and five times lower. Amorphous silicon modules are ideally suited to applications where there is a large amount of surface area available for mounting, since they perform much better in diffuse sunlight than mono or polycrystalline modules.



Courtesy of Solar Century

The table below shows typical conversion efficiencies of silicon based PV modules:

Efficiency (%)	Module type	Durability (yrs)
12-15%	Monocrystalline	25-30
10-13%	Polycrystalline	20-25
3-6%	Amorphous	15-20

Efficiency is a measure of the electrical energy output from the system. A lower efficiency means more PV modules are needed to produce the same electricity output.

Suitability to urban environments

Photovoltaics are perhaps the most suitable of all renewable energy technologies for widespread use in urban environments.

Because electricity is generated at the point of use, the energy loss and costs associated with transmission and distribution are avoided. There are however some important considerations regarding their selection and integration into urban areas.

In urban environments there is usually a limited amount of space available for mounting PV modules. In these situations mono or polycrystalline modules have the advantage over amorphous silicon because, being more efficient, less surface area is required to provide the same output. Conversely, amorphous/thin film modules can be deposited on a wide range of rigid and flexible substrates, making them ideal for integration into new-build dwellings.

A key advantage of photovoltaics in the urban environment is their potential to be integrated into the fabric of the building. No extra land space is required and the visual aesthetics of a building can be altered - either to be unobtrusive, or to give a clear indication of 'green' credentials.

In the urban environment, grid-connected PV is likely to be more practical and cost-effective than a stand-alone system. The system is connected to the local electricity network and any excess electricity not consumed by the household can be sold back to the electricity supplier. During periods when the modules are not generating, electricity will need to be imported. In these situations you should consult the District Network Operator (DNO) who will advise on appropriate options for connection.

PV modules are commercially available in a range of different types for integration into urban dwellings and locations.

They vary from traditional aluminium framed modules and roof mounted systems, to products like roof tiles and semi-transparent conservatory/atrium roof systems. The flexibility of the technology enables products to be used which have the same structural and weather properties as traditional construction materials. Furthermore, their modular construction allows any size of system to be installed.

Gwalia housing group at Llety Llanelli

Costs

The installed cost of a typical photovoltaic array for a dwelling is still relatively high. The total cost will vary significantly according to the module type, the application and the overall efficiency of the system.

The table below shows the area of array required, total installed cost, and energy output per year for a typical 1 kWp (kilowatt peak) polycrystalline PV array:

Array size (kWp)	Area of PV (m^2)	Total installed cost (£)	Energy saving (kWh)
1	10	4,000-6,000	800

A system of this size would be sufficient to supply the majority of the base load (the electricity required to run appliances and processes that are in constant use) for a typical UK dwelling.

Many PV installations, particularly in urban areas, will require regular cleaning to remove dust accumulation. In extreme cases, dust accumulation can cause power reduction of up to 10%. At low angles of tilt, debris could be trapped which could lead to shading of part of the array.

However systems can be designed and located so that they can 'self-clean' when it is raining. This can normally be achieved if the array tilt is at least 15 degrees.

Grants to reduce the cost of installing a photovoltaic system by up to 60% may be available from the DTI's Major Photovoltaic Demonstration Programme. See Further Information for more details.

Solar thermal systems (Solar Hot Water)

Basic principles

As well as converting incoming solar radiation into electricity using photovoltaic cells, energy from the sun can also be harnessed to provide domestic hot water.

These systems do not generally provide space heating, and are described as 'solar thermal' systems. They are among the most cost-effective renewable energy systems that can be installed on dwellings in urban or rural environments.

In a typical system, a heat transfer medium (generally a water/antifreeze mixture) travels through a series of heat conducting tubes known as a heat collector. During its circulation through the tubes, the fluid picks up heat which is then transferred to the domestic hot water supply as it passes through a coil in an appropriate storage cylinder.

Heat transfer system

Commercially available systems are either indirect (closed loop) or direct (open loop). With the more common indirect system, circulating fluid flows through the collector and transfers the heat to a hot water tank. A typical closed loop solar water heating system is shown in Figure 3.

With direct systems, water is heated as it is passed directly through the collector, and flows to the dwelling where it can be used for bathing, washing etc.

Direct systems can have higher efficiencies than indirect systems, but will have higher running costs, as the potential for scaling and corrosion of the internal surfaces can lead to increased servicing and maintenance.

Circulation system

Solar hot water (SHW) systems can be either active or passive in terms of the circulation method.

Active systems use an electric pump to circulate the heat transfer fluid (some installations use a small PV module to generate electricity for driving the pump). In a typical system a controller will compare the temperature of the solar collectors with the temperature of the water in the storage cylinder(s). If the collector temperature is hotter than in the storage cylinder, the controller will switch on the pump. The circulating fluid will then start to flow through the collectors and heat exchanger, thus heating the water in the cylinder. These systems are generally more efficient than passive systems but more expensive to buy and install.

Unlike active systems, passive systems do not use an electric pump to circulate the heat transfer fluid. Instead these systems rely on natural convection or water pressure to circulate the fluid through the collector to the point of use.

One type of passive system is known as a thermosiphoning system. Convection causes warm water to become lighter and rise naturally through the collector to a storage tank, which must be situated above the collector. Cooler water in the collector will flow down the pipes to the bottom of the collector, resulting in the circulation of water throughout the system.

These systems are relatively inexpensive but are rare in the UK. They can be difficult to control and consideration must be given to the space needed for storage of a large volume of water. Passive systems require less maintenance than active systems due to the absence of a pump - but can be less efficient.

Expansion and freeze protection

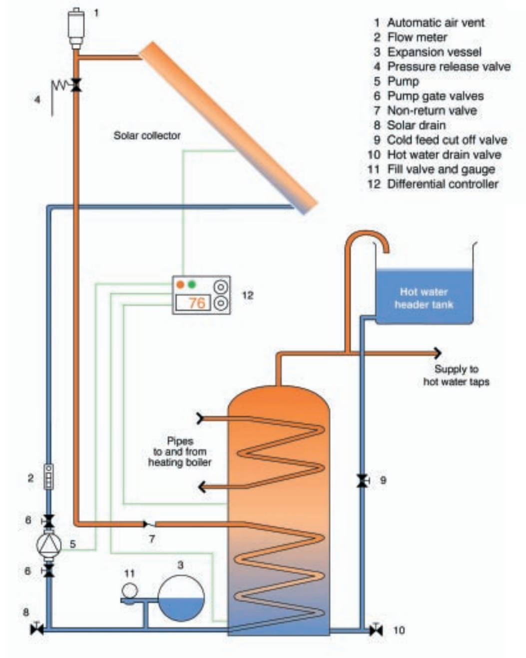
The circulating fluid in a SHW system tends to expand and contract as it warms and cools; therefore allowance needs to be made for expansion. Systems also need to incorporate a method of protecting the circulating fluids from freezing during winter.

Most domestic systems are pressurised (sealed) and require an expansion vessel and air vents. These systems rely on (1) the fact that the circulating fluid is under pressure to prevent the fluid from boiling, and (2) an appropriate antifreezing-freezing agent to protect the system from damage.

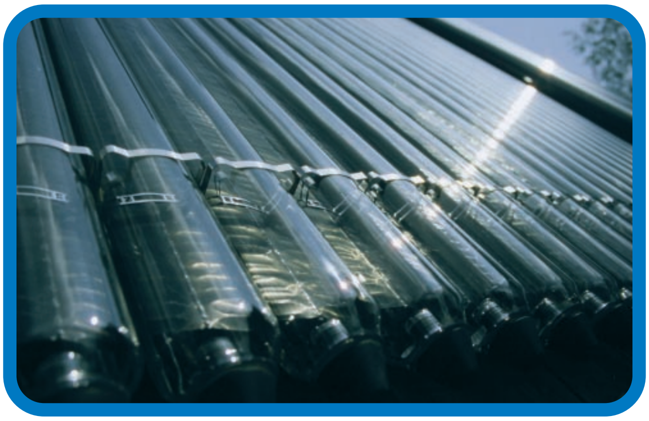
Drain back systems use a tank to store the circulating fluid when the system is not in use. Whenever the system is not collecting solar radiation from the sun or the ambient temperature is very low, a temperature sensor can switch off the pump and allow the fluid to drain back into the tank automatically. This helps protect the system from freezing and potential damage due to extremes of temperature during the summer months.

When considering the options for expansion and freeze protection for a specific application, always seek advice from a specialist consultant/installer. This will ensure that components such as the expansion vessel (where appropriate) are sized for use in all anticipated conditions, including stagnation under full sunlight.

Figure 3: Solar water heating system (Courtesy of AES Solar Systems Ltd)



Types of solar thermal collector
A basic solar thermal collector comprises of a translucent cover, an absorption plate, and the heat transfer system. In the UK, there are two main types of collector, known as evacuated tube and flat-plate.



(Source: Centre for Alternative Technology)

Evacuated tube systems
Evacuated tube collectors consist of rows of parallel transparent glass tubes, each containing an absorber tube covered with a selective coating. Selective coatings are made of materials which reduce radiation heat losses from the collector. This can significantly boost the efficiency of the collector.

Sunlight enters through an outer glass tube and strikes an absorber tube, at which point it converts into heat energy. This heat is then transferred to a liquid flowing through the absorber tube.

During the manufacturing process air is evacuated from the space between the two tubes, forming a vacuum. This vacuum greatly reduces heat loss from the system because there is no air to conduct the heat away.

Evacuated tube collectors have the benefit of the sun shining directly on the absorber for most of the day. Also, by adding or removing tubes, systems can be modified at a later date to fit in with potential changes in the hot water requirement. They perform well in both direct and diffuse solar radiation, which is why they are especially effective in the UK climate.

Whilst more efficient than the flat-plate type, evacuated tube collectors are inherently more expensive due to the complexity of their design and manufacture.

Flat-plate systems
Flat-plate collectors are the most common systems for domestic water heating. They generally consist of an insulated metal box with a glass or plastic cover and a dark or black coloured absorber plate.

The transparent cover allows the light to strike the absorber plate whilst reducing the amount of heat that can escape.

To further minimize heat loss, the sides and base of the collector are usually insulated.

The absorber plate is usually black because dark colours absorb more solar energy than light colours. Sunlight passes through the glazing and strikes the absorber plate. As with the evacuated tube collector, this has the effect of changing the incident solar radiation into heat energy. This in turn is transferred to the liquid passing through the collector. The tubes are arranged in parallel and attached to the absorber plate so that heat absorbed by the absorber plate is readily conducted to the liquid.

Absorber plates are often made from copper or aluminium, being good heat conductors. Copper is more expensive, but is a better conductor and less prone to corrosion than aluminium.

In common with evacuated tubes, many flat-plate collectors now have selective coatings to increase the temperature and efficiency attained compared to simple matt black absorber plates.

Suitability to urban environments
Like PV systems, solar collectors provide optimum performance when positioned in direct sunlight and located on sloped roofs with a southerly orientation.

Unlike photovoltaic cells however, the degree of offset from due south is not so critical, enabling correctly sized systems within approximately 45° of due south to provide a significant contribution to hot water demand. During the summer months a typical SHW system can achieve between 80-100% of hot water demand, although this will be considerably less in winter.

High-efficiency boilers should be used where applicable to provide auxillary 'top up' heating of the domestic hot water (DHW) supply. This is particularly important since there is a risk of legionella forming unless the household water supply is heated to 60°C at least once a day. This applies to ground source heat pumps as well as solar thermal systems.

There is a significant potential for SHW systems in urban areas, provided that roof spaces for the location of collectors are unshaded by neighbouring properties and obstructions.

Planning permission for installing a SHW system is not often required, but you should always seek advice from the local planning authority, particularly in the case of listed buildings.

Costs

Although the capital cost of installing solar water heating is high compared to conventional forms of domestic water heating, the fuel is free and running costs are generally nil.

An active system will require an electrically driven pump, but this electricity can either be provided by a 'green' tariff or a small PV module mounted close to the collector, together with a light sensor.

A typical domestic solar water heating system will be able to save 1,000–2,000kWh per year, which equates to approximately 50% of a household's annual domestic hot water needs.

Collector type	Collector area (m^2)	Total installed cost (£)
Flat-plate	3	2,000 - 3,000
Evacuated tube	3	3,000 - 5,000

Fixed grants of £500 may be available from the Government's Clearskies initiative to reduce the cost of installing a solar hot water system. See Further Information for more details.

Wind energy

Commercially available small scale wind turbines are generally more suited to rural areas due to siting and planning issues, as well as the higher average windspeeds more readily available.

However development work is underway on 'wind concentrators' in which the wind speed approaching a small scale turbine is accelerated, increasing the final power output. These devices may be commercially available in the future, and be suitable for adaptation to new and existing buildings in urban areas.

Local planning authorities normally need to give permission for the installation of turbines in urban areas and their advice should be considered at an early stage in larger projects. For grid connected systems in particular, assistance will be needed from the appropriate Distribution Network Operator (DNO) in order to meet relevant electrical connection requirements.

Other planning issues to be considered include the method of fixing turbines to buildings in order to eliminate vibration, the visual impact of the turbine and any associated noise whilst in operation.

More information on wind energy can be found in Renewable energy sources for dwellings in rural environments published by Energy Efficiency Best Practice in Housing.

Energy from the ground

It has already been shown how energy from the sun in the form of solar radiation can be utilised directly for domestic hot water pre-heat, space heating and electricity generation, by using solar thermal and solar electric technologies.

However, much of the solar resource in the UK will remain untapped by these technologies since it is not feasible to cover all the land area with photovoltaic arrays and solar collectors. The earth absorbs a large proportion of the incident solar radiation, which in the UK keeps the ground at a stable temperature of between 11-12°C all year round.

The temperature of the earth is therefore higher than the mean air temperature in winter but lower than the mean air temperature in summer. This is a readily accessible energy source for heating dwellings in the UK.

A heat pump extracts solar heat from the ground by 'moving' heat from one place to another and from a lower temperature to a higher temperature, to heat dwellings. It is essentially the same technology (in reverse) as a conventional domestic refrigerator.

Ground source heat pumps therefore utilise stored solar heat, and do not generally use deep geothermal heat generated by the earth's core.

Basic principles

There are three key elements to any ground source heat pump (GSHP) system:

- Ground heat exchanger
- Heat pump
- Heat distribution system

Figure 4 shows a typical system.

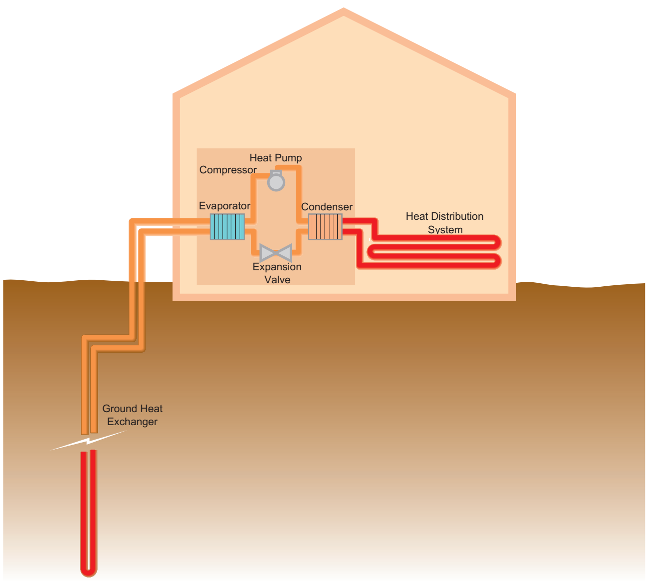


Figure 4: A typical ground source heat pump system

Ground heat exchanger
The ground heat exchanger is a loop or coil of pipe that is buried in the ground. A fluid consisting mainly of water mixed with antifreeze circulates through the loop and increases in temperature by absorbing heat from the surrounding soil.

Systems can be either closed-loop or open-loop, although the majority of domestic installations use an indirect circulation closed-loop system. A sealed loop of high density polyethylene pipe is buried horizontally or vertically in the ground, and a water/antifreeze mixture is pumped directly through it.

A more efficient alternative is a direct circulation or direct expansion (DX) system. In this system, an additional heat exchanger and pump are no longer required, since the refrigerant from the heat pump is circulated through a copper ground coil. Although a shorter ground loop can be used - reducing the cost of installation – the downsides are higher cost of the pipe material, the large amount of refrigerant required, and the risk of leaks from the refrigerant system.

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The heat pump
A heat pump works by driving a working fluid or refrigerant around a circuit which comprises of an evaporator, compressor, condenser and an expansion valve. As heat is absorbed by the heat source, the refrigerant changes its state by evaporation from a liquid to a gas. The refrigerant is now at a low temperature and pressure; it enters the compressor where both the temperature and pressure are increased as a result of work done on the refrigerant. The gas now enters the condenser where the heat absorbed by the collector coil is released, to be used in the dwelling via the heat distribution system.

The refrigerant, still in the form of a gas, but reduced in pressure and temperature, is throttled back further in the expansion valve before recommencing the cycle by absorbing more heat from the collector.

The compressor runs on electricity and consumes approximately one unit of electricity for every three units of heat energy produced. However, the total amount of heat energy delivered to the dwelling is equal to the energy required to run the heat pump plus the energy extracted from the soil. Therefore GSHP systems typically achieve overall efficiencies of between 200-400% depending on the operating conditions.

The heat distribution system

A distribution system is needed to transfer the heat extracted from the ground by the heat pump. The heat is often in the form of hot water, and is distributed around the dwelling by radiators or a low temperature underfloor heating system. A typical underfloor heating system is shown on the picture below.

The difference in temperature between the heat source and the distribution system is a key factor in determining the overall efficiency of the heat pump. The smaller the difference, the higher the coefficient of performance (COP) will be.

This is why GSHP systems, with their more stable source temperatures, are generally more efficient than other forms of heat pump. It is also important to use the lowest possible temperature distribution system to maximise the COP.

Suitability to urban environments
In urban environments GSHP systems are at their most cost-effective in new-build properties where high levels of insulation have been achieved. Where there is a low heating demand, underfloor heating and other low temperature heating distribution systems become possible options.

The choice of vertical or horizontal system depends on the land area available, local ground conditions and excavation costs.

Vertical collectors are inserted into boreholes (usually between 15-20m deep) and are ideally suited to dwellings with smaller gardens.

In contrast, horizontal collectors require relatively large areas of land for the trench, which for a medium detached new-build house is typically 1-1.5m deep and 40-50m in length. The length of trench required can be reduced by 70% to 80% if the pipe is laid in a series of overlapping coils. This can be placed vertically in a narrow trench, or horizontally in a wider trench.

Horizontal collectors are therefore less suited to urban applications where land availability is usually limited.

Costs

The initial capital cost of installing a ground source heat pump system is usually higher than other conventional central heating systems; a large proportion of the outlay will be for the purchase and installation of the ground collector. See table below for indicative system costs, including installation and commissioning per kW of heat output.

System type	Ground coil costs (£/kW)	Heat pump cost (£/kW)	Total system costs (£/kW)
Horizontal	250-350	350-650	600-1,000
Vertical	450-600	350-650	800-1,250

The figures above do not take into account the cost of installing a suitable distribution system as this will tend to be application specific. However, an additional cost of between 50-75% of the above system figures can be expected.

By increasing the insulation to roofs, walls and floors beyond the requirements of the building regulations, the heating requirement and therefore the total system cost (including the distribution system) can be reduced significantly.

The running costs of GSHP systems arise from electricity requirement for: (1) operating the compressor in the heat pump, and (2) the pump for the circulating fluid in the ground collector. To minimise costs, a system with a good coefficient of performance (COP) should be selected and the system operated on a dual tariff (which includes off-peak or economy seven etc). Costs could be reduced further by coupling the GSHP system with PV modules or a small wind turbine to provide the necessary electricity.

When operated in this way, GSHP systems will have annual running costs comparable with the most efficient of the currently available natural gas condensing boilers.

Minimal extra cost will be incurred due to servicing and maintenance. There are only two moving parts: a compressor, which is a sealed unit with a lifetime in excess of 15 years, and a circulating pump which is unlikely to be guaranteed for more than one year. Ground loops made from polyethylene pipe should last for more than 50 years. Systems generally need no regular servicing although specific requirements should be checked with the equipment manufacturer.

Biomass fuel

Basic principles

Biomass or wood burning systems differ from other renewable energy sources because they emit carbon dioxide (CO_2) when they are burnt. The amount released is equal to the carbon absorbed when the tree was growing, so the process is essentially carbon neutral. Trees and plants achieve this by photosynthesis, whereby CO_2 and water are absorbed from the surroundings and converted by energy from sunlight into the sugars, starches, and cellulose which make up the vegetable matter. The basic carbon cycle is illustrated in Figure 5 below.

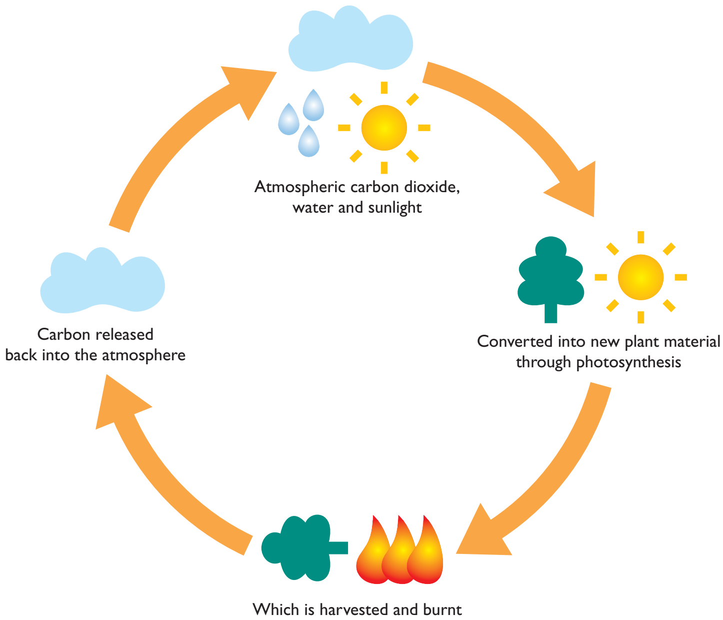

Figure 5: The Carbon Cycle

Although no more CO_2 is emitted than originally absorbed, the combustion process itself can be extremely inefficient if not properly controlled. Burning logs in open fires can mean that up to 85% of the heat generated is lost to atmosphere. Controlling the process, and in particular the air supply, is a key factor in ensuring that this heat is not lost. Modern wood burning stoves can achieve efficiencies of 80-90%.

Furthermore, in order for biomass to be a truly renewable energy source, the fuel must come from a sustainable source (i.e. it is replenished) and should be used in close proximity to where it has been grown. Even allowing for emissions of CO_2 in planting, harvesting, processing and transporting the fuel, replacing fossil fuel energy with wood will typically reduce net CO_2 emissions by over 90%.

Types of fuel

There are few sources of energy as versatile as wood. It can be burned in a number of different forms and in different types of appliances. It can be used to heat an entire house, just one room, for cooking, or even to provide domestic hot water.

For domestic small scale applications, three different types of wood fuel are generally used: logs, pellets and woodchip. The graph in Figure 6 shows the approximate amount of wood fuel required to meet the total space and hot water energy demand of a dwelling.

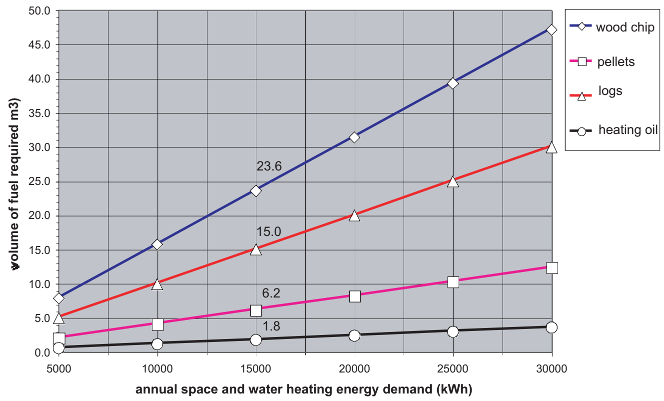

Figure 6: Graph showing volume of fuel required against annual domestic heating energy demand (Source: Centre for Sustainable Energy)

Logs

Wood fuel in the form of logs is one of the simplest, cheapest and quickest methods of producing fuel ready for use by the consumer. As most of the weight of freshly felled timber is due to its moisture content (between 35-60% of the total weight), it is usually preferable to buy the fuel by volume than by weight. Wood with high moisture content will produce significantly less heat than seasoned timber.

Important factors affecting the amount of heat produced when burning are the time of year when the wood is felled and the length of time given to seasoning of logs. Wood felled in the winter months contain significantly less moisture than during the growing seasons of spring and summer, reducing the time needed for seasoning.

Pellets

Although gaining in popularity in the UK, the use of wood pellets for space heating is well established in countries such as Sweden, Austria, Denmark and North America. Pellets can be manufactured from a variety of sources, but typically in the UK they will be sourced from compressed waste sawdust, pallets or recycled untreated wood waste.

Their main advantage over other wood fuels is their energy density which is over twice as much as logs and nearly four times greater than woodchip. This substantially reduces the volume of fuel required to produce the same amount of heat.

Woodchip

Short rotation coppice, recycled wood waste, park waste, and tree thinnings are all potentially good sources of woodchip fuel. The energy density of woodchip is significantly lower than pellets and logs, although this is highly dependent on moisture content and particle size.

Types of system

Stoves

The traditional log burning room heater or stove is ideal for smaller domestic applications (between 2-12kW), and usually consumes wood fuel in the form of logs or pellets.

Figure 7: A pellet stove with back boiler (Source: Centre for Sustainable Energy)

They are most commonly used for providing direct space heating in conjunction with a gas or oil central heating system, although in suitable, well insulated housing, two or three room stoves may be able to provide the entire heat load requirements.

Recent improvements in design and production methods mean that many models are approved for use in smokeless zones and can be fitted with back boilers for providing domestic hot water, as well as space heating.

Larger scale boilers

In larger households where the heat demand is greater than 15kW, stoves and room heaters will be unlikely to provide adequate heat economically. For these applications, boilers which can be fed by logs, pellets or wood chip are more suitable. They usually provide both space and water heating as they can be installed with a hot water tank acting as a thermal store.

This enables the boiler to burn fuel at a controlled and constant rate, whilst providing a ready supply of heat whenever required. Due to the low energy content of woodchip compared to pellets and logs, more storage space will be required to accommodate woodchip; therefore woodchip boilers are less suited to domestic applications in urban areas where space is restricted.

Community/district heating
Larger urban applications such as social housing and multi-dwelling developments can present the opportunity for automatic wood chip boilers with capacities ranging from 20kW to over 1,000kW.

When burning fuel with high moisture content, the boiler plant can become more technically complex and expensive. These boilers are generally designed for use with woodchips with a moisture content of between 25-35%.

Large scale boilers will perform at their maximum efficiency when operated at, or close to, total capacity. They are therefore best suited to providing base-load heat demand, with fossil-fuelled boilers operating as an auxiliary back-up to fulfil peak load demand.

As technology advances, models are becoming available with sophisticated controls allowing the boiler to 'modulate' and follow the heat load as it varies, without compromising efficiency and performance.

Suitability to urban environments
Availability of specific forms of wood fuel is a major factor when considering the suitability of biomass heating. Like any fuel, the security of long term supply needs to be considered, as does the supply infrastructure itself, which in the case of most wood fuels, is yet to become fully established.

Storage space for the wood fuel can be a major issue when specifying or designing a system for a domestic application in an urban area. In some automated handling systems, the store needs to be adjacent to the boiler and this can make retro-fitting to existing houses difficult.

Due to their higher energy density it is much more economical to transport wood pellets to the point of sale or use, than woodchip or logs.

Further planning issues of particular importance in urban dwellings include: (1) only selecting appliances that burn the fuel cleanly, and (2) planning implications due to the installation of a suitable flue (this may not be required if an existing chimney can be adapted for use).

Costs
The capital costs of wood burning systems, irrespective of type, are related mainly to the size of system chosen. Installation and commissioning costs will generally be fairly constant whatever the selected system and its capacity.

Some guideline costs for small and large scale biomass heating systems are shown in the table below.

System type	System cost per kW) (£)	Total* cost (£)
Room heater/stove with automated wood pellet feed	-	2,400-2,600
15 kW boiler system burning logs or pellets	280-315	4,200-4,700
15 kW boiler system burning woodchip	585 - 615	8,800-9,200

** includes capital outlay, installation and commissioning but excludes cost of distribution system and/or radiators*

The total outlay could vary considerably from these figures shown above. They will depend on whether the system uses a boiler or room heater/stove, manual or automatic fuel feed, and an integral or separate storage facility.

Fuel for biomass heating systems still needs to be purchased, unlike other renewable sources such as solar hot water (solar thermal). Fuels like woodchip and logs still compare favourably with coal, oil and LPG, although pellet fuel cannot compete with current gas prices, particularly for individual household systems.

The payback period for biomass systems will depend on the type of fuel being used, as well as the fossil fuel which is displaced. Generally speaking, systems pay for themselves over their lifetime.

Stand-alone and grid-connected systems

As renewable energy technologies, photovoltaics and small scale wind turbines can operate either as stand-alone systems (off-grid) or as grid-connected systems.

Stand-alone

Stand-alone systems operate completely independently of the national grid. They are connected directly to a battery or array of batteries which stores the electricity generated and acts as the main power supply. The size of the battery array will determine the amount of energy that can be stored, and hence the time that appliances will run for if there is no wind or solar radiation.

An inverter is used to convert the direct current electricity produced by the turbine or PV array into usable alternating current for domestic use. The size of the inverter will determine the number of appliances that can run concurrently.

An outline of a typical stand-alone system for a small-scale wind turbine is shown in Figure 8.

Many systems currently in use operate in conjunction with an auxiliary generator to provide back-up during periods of low wind speeds.

In such systems the generator can be used at optimum load for short periods to charge the batteries, rather than constant direct use at varying loads.

Grid-connected

Grid-connected systems have the advantage of not requiring a battery array to store energy. However, an inverter is still needed to convert DC power to AC at a quality and standard acceptable to the grid.

Any unused or excess electricity can be sold to the local electricity supply company and exported to the grid. This may include net metering arrangements which should be considered if appropriate and available.

When the user is exporting excess electricity to the distribution network, it can offset the times when there is a need to import electricity because demand exceeds generation. Over a specified period of time, the net of the electricity generated and consumed is calculated and the customer billed for the balance at the usual unit price.

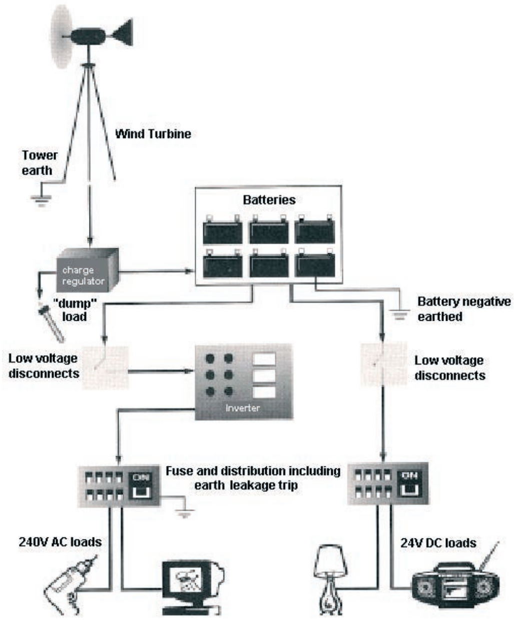

Figure 8: A typical stand-alone renewable energy system (Source: Centre for Alternative Technology)

Renewables and Intermittency

When directly compared to fossil fuel, some renewable energy sources have to deal with the problem of intermittent generation.

Intermittent sources only generate electricity when the environmental conditions are right (such as when the wind is blowing, or the sun is shining), and since large volumes of electricity cannot currently be stored, there may be additional costs when incorporating these sources onto the national grid.

Stand-alone systems can bypass this problem by being independent and relying on batteries for electricity storage. With ground source heat pumps and solar hot water systems, heat energy transferred to water can be stored in a tank for later use.

However, grid-connected systems (without a method of storage) will need to import electricity from the grid. There is also the difficulty in assessing resources. Variable sources of energy result in mean values or long-term annual or monthly averages, being required to predict the actual quantity of resource available.

Additionally there is a need for auxiliary energy systems to enable us to meet our energy needs when insufficient energy is available from a renewable source. This can take the form of either a fossil fuel system or electric immersion heater, or another form of renewable energy - e.g. a wind turbine used in conjunction with a PV panel.

Technologies for the future

Micro-CHP

Micro-CHP (Combined Heat and Power) involves an engine driving an electrical generator that allows individual homes to generate a proportion of their own electrical supply, whilst also supplying heat and hot water. Micro-CHP systems and products which can provide enough heat for domestic heating and hot water are gradually becoming commercially available.

Supplementary electrical power is usually required from the grid at times of peak use; the unit will export power when the demand from the dwelling is less than that generated.

Although the technology is yet to be fully established, micro-CHP systems have the potential to make a substantial saving in CO_2 emissions from the home.

Fuel Cells

All fuel cells share the fundamental principle of combining hydrogen and oxygen to produce electricity, heat and water. Like batteries, they can be recharged whilst drawing power from it. However, they use a specific fuel (such as methanol, phosphoric acid) rather than electricity to achieve this.

Although certain types of fuel cell are currently considered to be commercially viable, more research and development is needed on the infrastructure and technology before more widespread uptake can occur in domestic applications.

Nevertheless significant potential does exist, since fuel cells can be connected to the grid to provide supplemental power, or can operate independently from the grid for on-site generation in rural areas where grid access is unavailable.

Fuel cells can only be truly referred to as a 'renewable energy source' if the electricity used is itself generated by a renewable energy source such as a photovoltaic array or a wind turbine.

Further reading

Relevant Energy Efficiency Best Practice in Housing publications

BedZED – Beddington Zero Energy Development, Sutton (GIR89)

Building a sustainable future – homes for an autonomous community (GIR53)

Domestic ground source heat pumps (CE82)

Heat pumps in the UK – a monitoring report (GIR72)

Passive solar design – the Farrans study (GIL25)

Renewable energy in housing – case studies (CE28)

Summary of specifications for energy efficiency in new dwellings in England and Wales (CE12)

Summary of specifications for energy efficiency in new dwellings in Northern Ireland (CE24)

Solar hot water systems in new housing – a monitoring report (GIR88)

The Hockerton housing project – design lessons for developers and clients (CE15)

Renewable energy sources for dwellings in rural environments (CE70)

References

1. EU Renewables Directive (2001/77/EC), October 2002
2. Renewables Obligation (Statutory Instrument 2002/914), April 2002
3. Renewables Obligation Scotland (Scottish Statutory Instrument 2002/163)
4. Energy (Northern Ireland) Order 2003 (Statutory Instrument 2003/419 N.I. 6)

Further information

Grants - prospective grants for renewable energy technologies are now available:

www.est.co.uk/solar for information about photovoltaics

www.clear-skies.org for details on grants in England and Wales for biomass, ground source heat pumps, micro-hydro, solar water heating and wind energy

www.est.org.uk/schri has information on grants in Scotland for wind energy, micro-hydro, ground source heat pumps, automated wood fuel heating systems and solar water heating

For further information on the technologies covered in this guide see the following websites:

Photovoltaics
British Photovoltaic Association
www.pv-uk.org.uk

Solar thermal
Solar Trade Association
www.solartradeassociation.org.uk

Wind turbines (small scale)
British Wind Energy Association
www.bwea.com

Ground source heat pumps
The UK Heat Pump Network
www.heatpumpnet.org.uk

Heat Pump Association
www.feta.co.uk

IEA Heat Pump Centre
www.heatpumpcentre.org

Groundswell newsletter
www.earthenergy.co.uk

Biomass
NEF Renewables – logpile website
www.greenenergy.org.uk/logpile

British Biogen – Trade Association for the UK Bioenergy industry
www.britishbiogen.co.uk

Action Energy
Information on energy efficiency in non-domestic buildings
Tel: 0800 585 794
www.actionenergy.org.uk

Energy Efficiency Best Practice in Housing

Renewable energy sources for homes in urban environments

Energy Efficiency Best Practice in Housing

Helpline: 0845 120 7799
Fax: 0845 120 7789
Email: bestpractice@est.co.uk
Web: www.est.org.uk/bestpractice

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