TEHVA
The Electric Heating & Ventilation Association

DOM 9: GUIDE TO THE DESIGN OF ELECTRIC WATER HEATING SYSTEMS

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Introduction

Electricity can be a clean, quiet, efficient and convenient way of heating water. Whether it is for small quantities of water from a sink heater or an instantaneous shower or whether it is for larger quantities for general household use, there is a wide variety of products and methods of heating the water economically. Where smaller, and infrequent quantities of water are required, convenience and space are generally the overriding factors to be considered, so accordingly storage is not required and the tariff applying would be that applicable at the time of use. However, where larger quantities are required, hot water cylinders would be used to store the water, which would generally be heated by utilising available off-peak tariffs.

Typically, electricity suppliers offer a 7-hour night tariff and some may also offer a 10-hour tariff which provides periods of off-peak supply during the day, however, not all suppliers offer this tariff, so the availability should always be taken into consideration when changing energy supplier.

The following systems are included:

a) Hot water storage systems
b) Air to water heat pumps
c) Thermal stores
d) Solar water heating

This guide considers the principles of the design of hot water heating rather than detailed design guidance, particularly with regard to heat pumps and solar water heating.

Hot Water Storage Systems

Vented/unvented hot water cylinders

The most common hot water system is the open vented cylinder, where the pressure required to drive the hot water to the taps is provided by the height of the cold water storage tank above the cylinder. The cold water tank is usually located in the loft. A simplified diagram of an open vented hot water cylinder layout is shown in Fig 1.

The cylinders must comply with relevant British Standards, including BS 1566: 2002.

When pressurising the hot water cylinder with a cold water tank is not easily achievable, or where higher pressures and flow rates are required to enjoy the benefit of mixer showers and continental style taps, an unvented hot water cylinder may be installed. In this case the cylinder is pressurised by the incoming mains cold water. Because the mains pressure can be much higher than a vented cylinder can withstand, pressure reducing valves and safety devices have to be installed. A simplified diagram of an unvented hot water cylinder layout is shown in Fig 2a. A diagram of an unvented hot water cylinder layout with internal expansion is shown in Fig 2b. Unvented cylinders must comply with Building Regulation G3, compliance can be shown by approval to an accredited test regime (for example as operated by the British Board of Agrement, the Water Research Centre or KIWA) or BS 7206.

Unvented cylinders typically have two factory fitted immersion heaters. Each immersion heater must be separately thermostatically controlled. The lower element has to be capable of heating at least 85% of the cylinder contents and the upper element has to be capable of heating at least 60 litres of water. The lower element is connected to the off-peak electricity supply and the upper element to the on-peak for boost operation. The positions of the immersion heaters are intended to assist the efficiency and economics of off-peak water heating. Open vented cylinders would normally also have two immersion heaters, although these are frequently fitted at the time of system installation. The thermostat settings are similar to those for unvented systems.

In order to achieve maximum efficiency it is necessary to maintain good temperature stratification of the water within the cylinder. A baffle or deflector on the cold inlet may be required in order for this to be achieved, as it will prevent the incoming cold water from causing turbulence and lowering the temperature within the cylinder.

Fig 1 – Typical cistern fed heated vented hot water storage system

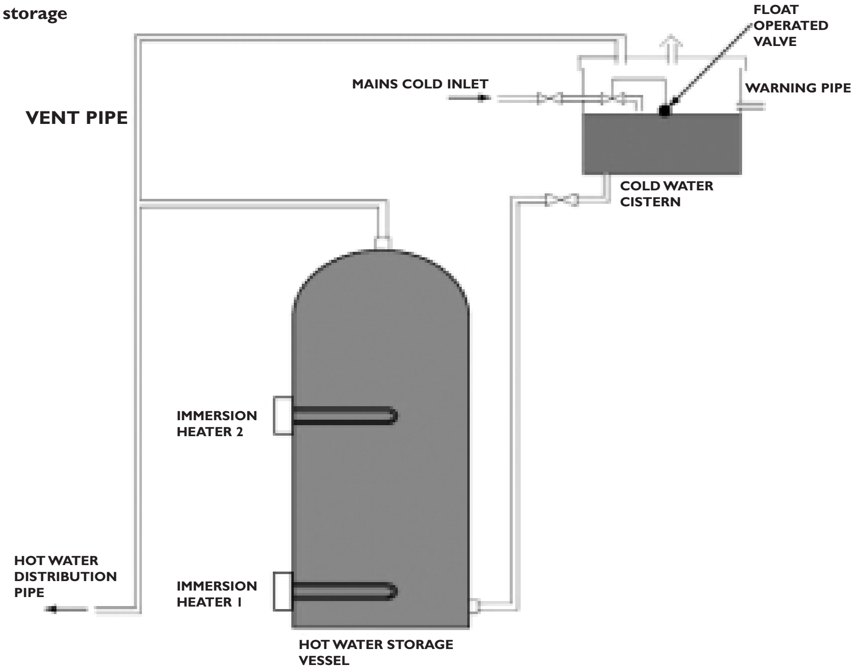


Fig 2a – Typical directly heated unvented hot water storage system with external expansion volume

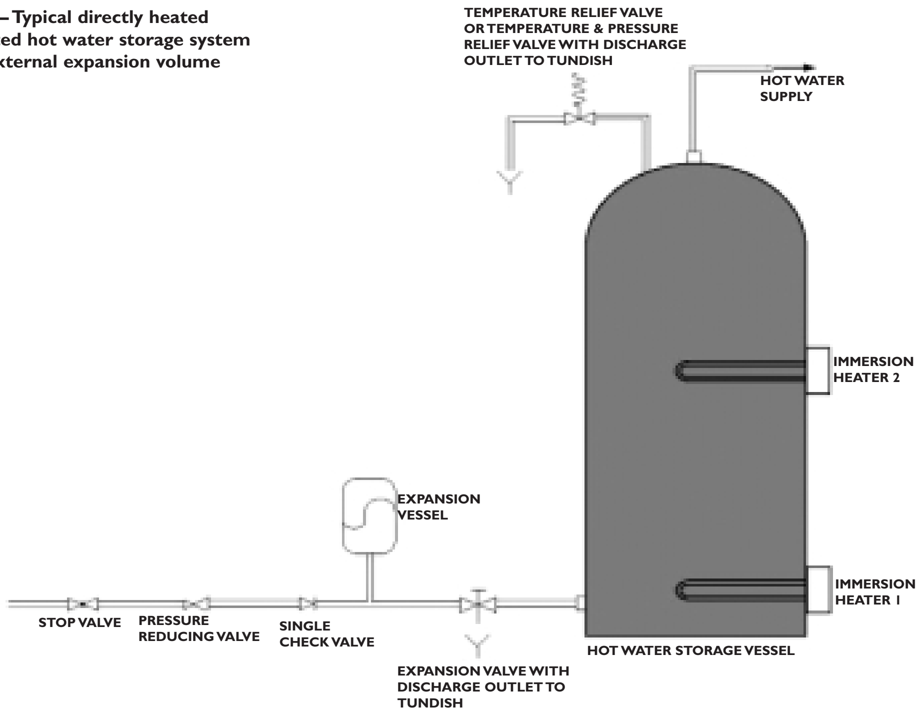
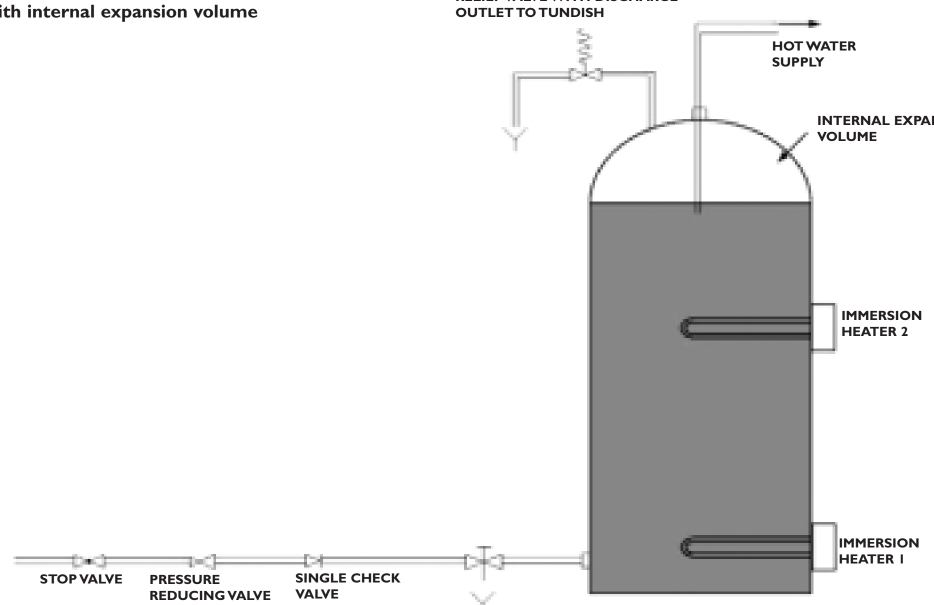


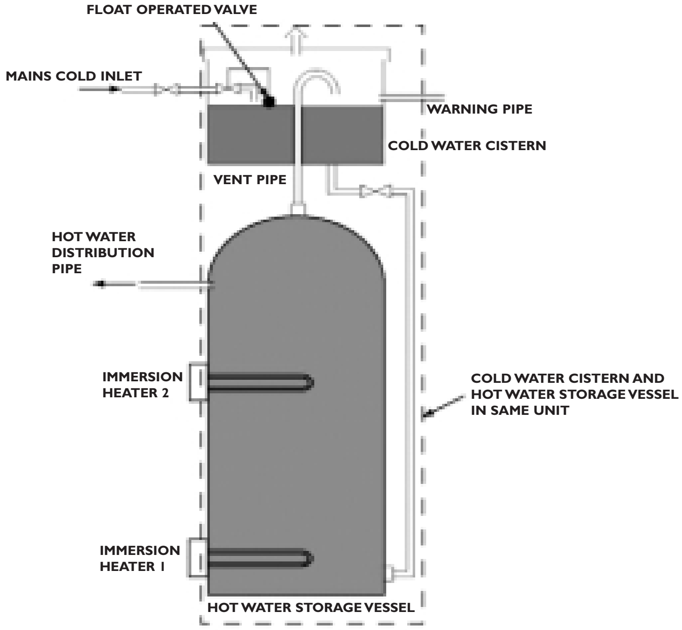
Fig 2b – Typical directly heated unvented hot water storage system with internal expansion volume



Combination Units

A combination unit is a hot water cylinder with an integral cold water feed tank situated immediately on top of it. Combination units are installed primarily in dwellings that may not have a cold water cistern available for pressurising a hot water cylinder and where the householders may not wish to have an unvented system. The majority of combination units are replacements for existing units and are selected as an economic like-for-like installation. Units should be positioned such that there is always sufficient head to supply a good flow of water to the hot taps. In practice the combination will often need to be placed on a plinth so that the top of the unit is as high as possible. A simplified diagram of a combination unit layout is shown in Fig 3.

Fig 3 – Typical vented combination hot water storage system



Insulation

It is essential that cylinders are well insulated to minimise heat losses. Current Building Regulations state that the 24-hour heat losses in kWh from insulated cylinders must be no more than:

$$1.28 \times (0.2 + 0.051V^{2/3})$$

where V is the nominal water capacity of the cylinder in litres

This equates to the losses shown in Table 1.

Table 1 – Maximum heat loses from insulated cylinders

	Cylinder size		
British Standard rating	BS7	BS8	BS9E
Cylinder capacity (litres)	120	144	210
24-hour max heat loss (kWh)	1.84	2.05	2.56

Immersion heaters

Domestic immersion heaters are typically rated at 3kW, although lower ratings are available, particularly as replacements for existing heaters. In hard water areas, calcium carbonate is deposited as the water is heated, resulting in the well-known scale formation. This can build up on an immersion heater giving some measure of protection from corrosion. If the scale builds up too much however, the heating element overheats and premature failure can occur. Scale builds more quickly at temperatures in excess of 60°C and thermostat settings should not generally exceed this unless using immersion heaters with a metal sheath having low surface adhesive properties, for example titanium. Titanium sheaths should also be used in areas with naturally occurring soft water, owing to the presence of free oxygen and carbon dioxide, which is acidic and aggressive to common metals. Immersion heaters should comply with BS EN 60335-2-73: 1997 or be specifically designed for and tested as part of the water heater to which they are fitted.

Controls

Each immersion heater has its own thermostat. The top heater, used for a boost if the off-peak heated water has been used up, is generally set at 60°C, whilst the lower heater, used for heating the whole cylinder at the off-peak rate, is set at 65°C. The lower heater thermostat is set at the higher temperature, firstly to obtain the maximum storage, without risking dangerously high temperatures; and secondly, to allow for the very small drop in temperature of the water during the day, due to standing heat loss and the introduction of cold water to replace the hot water that has been used.

The top immersion heater does not switch on automatically as soon as the temperature at the thermostat drops below 60°C, as this would restrict the amount of off-peak charge required to heat the cold water in the cylinder, thereby increasing the on-peak use and therefore the running costs. When householders are aware that the hot water storage has been depleted, they manually operate a one-hour boost on the controller, which will be sufficient to heat the top section of the cylinder without the risk of forgetting to switch it off.

During installation it is recommended that the settings of any water heating time controls are matched to the electricity supply tariff switching times and usage/occupation requirements, or the metering equipment itself directly switches the water heating circuit. This is to avoid the risk of time slippage, which could result in on-peak energy being used – unnoticed by the householder – increasing running costs. A schematic wiring diagram of a hot water controller is shown in Fig 4.

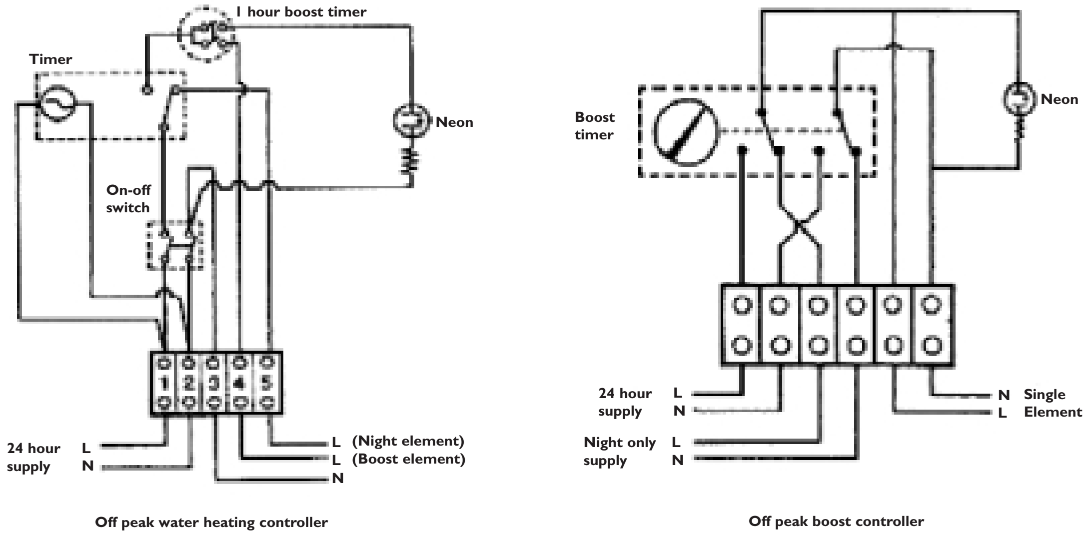


Fig 4 – Internal wiring diagrams for off peak water heating controllers

Cylinder sizes

If hot water is supplied using an off-peak tariff then it is usual to install a 210-litre cylinder, this will minimise the amount of on-peak use, which may be necessary from time to time. If smaller dwellings are specifically designed for low occupancy, such as sheltered accommodation, then smaller sizes of cylinders can be used. Also, if a 10-hour tariff is available, a smaller cylinder size may be used. The 10-hour tariff usually provides 5 hours of off-peak electricity overnight and two periods of off-peak during the day. This means that a smaller quantity of water needs to be stored as it can be heated at more frequent intervals. For similar sized cylinders on the two different tariffs, the cylinder on the 10-hour tariff will use significantly less electricity at the on-peak rate, as shown in Table 2.

Table 2. Comparison of on-peak energy consumption

Occupancy	Cylinder size	Proportion of on-peak energy (%) 7-hour	10-hour
2 Persons	120 litres	13%	7%
	144 litres	10%	0
	210 litres	3%	0
3 Persons	120 litres	17%	10%
	144 litres	14%	1%
	210 litres	4%	0
4 Persons	120 litres	22%	14%
	144 litres	17%	2%
	210 litres	6%	0

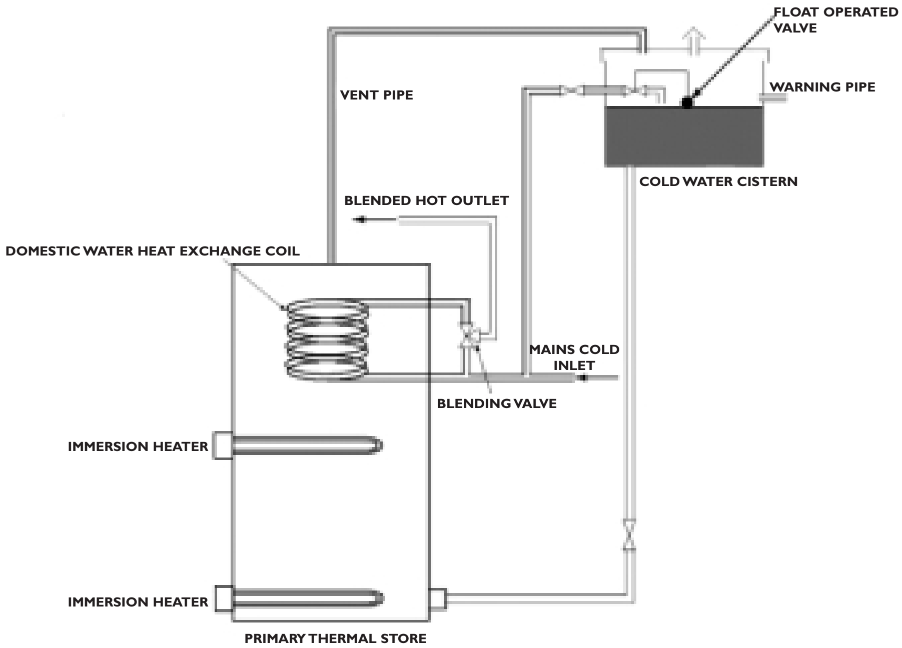
Thermal stores

A thermal store is a cylinder, or rectangular storage tank, with a primary store of water, which is heated on available off-peak tariffs. The heated water remains in the vessel; it is not intended for end use. Mains cold water is then circulated through a heat exchanger within the vessel and delivered to the taps. The thermal store is helpful where there is an insufficient head of water to provide adequate hot water supply to the taps and householders do not wish to have an unvented hot water supply system.

In order to obtain maximum storage capacity, the primary water can be heated to temperatures in excess of those for standard open vented cylinders.

Safety devices will prevent water with too high a temperature from being delivered to the taps, particularly when a tap is first opened. As the temperature of the water inside the vessel drops, so the flow rate will reduce to enable the water at the taps to maintain the required temperature. For more detailed information on thermal stores the Water Heater Manufacturers Association has produced a guide entitled *Performance Specification for Thermal Stores*. A simplified diagram of a thermal store is shown in Fig 5.

Fig 5 – Thermal store system for domestic hot water



Air To Water Heat Pumps

Domestic heat pumps are electrically driven machines which utilise environmentally free heat existing in the air, water or ground. A vapour compression cycle boosts the temperature of the free heat to a higher, more useful level so that it is capable of supplying sufficient heat to provide space and/or water heating to a dwelling. The heat is transferred to a water circuit, which allows it to be circulated as required. The prime advantage of heat pumps is that, depending on the application, they can operate with efficiencies ranging from 200 to 500%. The efficiency of a heat pump is generally referred to as the coefficient of performance (CoP), and rather than expressing it as a percentage, such as 350%, it is usually expressed as having a CoP of 3.5. This means that for an energy input of 1 kWh, the heat output is 3.5 kWh. This guide focuses on air source heat pumps supplying hot water only. If hot water is to be provided from the same unit that supplies the space heating, then ground source heat pumps are frequently used; for further information on ground source heat pumps, contact the Heat Pump Association (HPA).

Storage cylinders

The hot water storage cylinders for use with air to water heat pumps would generally be indirect cylinders, enabling the primary water supplied by the heat pump to circulate through the coil. As the heat from the heat pump is available economically throughout the day, a 144-litre cylinder would be sufficient. However, if full advantage of the off-peak tariffs is to be achieved the larger 210-litre cylinder could be used. Insulation requirements are the same as for direct cylinders.

Environmental benefits

Because of the very good coefficients of performance that can be achieved with air to water heat pumps, carbon dioxide (CO_2) emissions are greatly reduced to the extent that CO_2 emissions from heat pumps can be significantly less than those from either gas or oil fired boilers. With this performance heat pumps are of great benefit in complying with Building Regulations.

SAP currently recognises air to water heat pumps for space heating and specifies a CoP of 2.5 for their average seasonal performance. However, as an air to water heat pump dedicated to supplying hot water only would be operating throughout the year rather than just in the cold weather, it should achieve a significantly higher CoP because for the summer months the external temperature will be much higher. The higher the heat source, the greater will be the CoP of the heat pump.

The environmental benefits of air to water heat pumps are also recognised by the Chancellor of the Exchequer by reducing the VAT on them to 5%. This is applicable when they are used in residential buildings or in buildings used solely for charitable purposes.

Controls

When providing the water to heat the cylinder, the temperature of the primary water must be within the range of 60-65°C. If the heat pump is not capable of supplying water at this temperature, then supplementary heating would be installed; this would generally be in the form of an immersion heater. An immersion would very often be installed for emergency use in case of a break down, as is the case with gas or oil fired boilers when providing hot water.

The controls for the hot water cylinder are simple. They include a thermostat to switch on the heat pump as and when required. The thermostat is normally positioned about one third up the cylinder to allow a reasonable quantity of water to be heated at once, rather than cause the heat pump to cycle too frequently. A hot water timeswitch is advantageous in making maximum use of available off-peak tariffs.

Solar Water Heating

For even greater environmental benefit, water heating can be provided by solar panels. Because of the complexities of a solar water heating system, it is essential that the manufacturers are fully involved throughout the design and installation process as there are a number of factors to be considered, including the positioning of the solar collectors in relation to shading, collector performance requirements, primary circuit fluid considerations, circulation pump requirements and heat exchanger performance.

The solar collectors used for domestic water heating would normally be either flat plate collectors or evacuated tubes. Ideally they would face south for maximum benefit, although if they face south-east or south-west the effectiveness will not drop noticeably. The optimum tilt angle is usually in the range of 20-50° and most systems follow the roof pitch. Even if the collectors face due east or west, they should still produce sufficient hot water, although avoiding shading becomes more important.

The hot water cylinder would have a supplementary source of heating in the event of insufficient heat being provided from the solar panels. The same fuel that supplies the space heating would usually supply the supplementary heating to the hot water. If this were electricity then the supplementary heating would be an immersion heater. Care would have to be taken to prevent the supplementary heating from taking priority for heating the water.

Typically, the indirect coil from the solar collector is located at the bottom of the cylinder, so that the complete volume can benefit from this 'free' heat, or preheat incoming cold water during poorer solar conditions. The cylinder therefore has a dedicated solar heated volume. The supplementary heating heats the upper section of the cylinder so that if it is necessary to switch it on, it will not inhibit the use of solar heating to any great extent. Good cylinder insulation is again essential to maintain water storage temperatures and to limit the introduction of supplementary heating. An electronic controller constantly compares the temperature of the solar collectors with the temperature in the cylinder, and whenever the collectors are hotter than the cylinder, the controller switches on the system's circulating pump.

A simplified diagram for typical solar water heating is shown in Fig 6. Further information on solar water heating can be obtained from the Solar Trade Association.

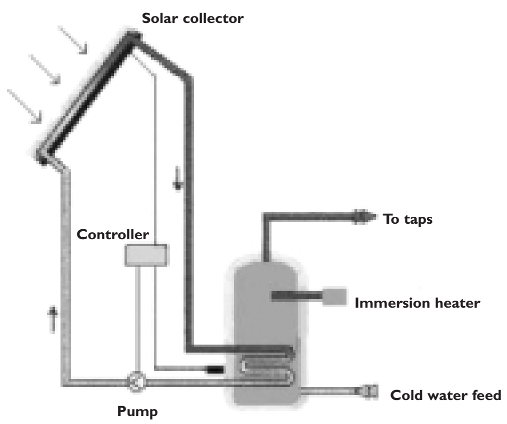


Fig 6 – Schematic diagram of solar heating for hot water supply

Point-of-Use Water Heating

Point-of-use water heaters are usually fitted into existing dwellings. They are particularly useful where extensions and alterations are being undertaken, as they need only a cold water supply, usually mains cold water. Probably the most common point-of-use water heater is the instantaneous shower, which is often used on the first floor of two storey dwellings as the head pressure from the cold water cistern is sometimes insufficient to provide a high enough water flow, and can be a more economic solution than the power shower.

Point-of use water heaters can also be appropriate for the growing markets of holiday lets and second homes, where usage can be very varied and irregular.

References

Heat Pump Association
2 Waltham Court, Milley Lane, Hare Hatch, Reading, Berkshire, RG10 9TH
Tel: 0118 940 3416

Solar Trade Association
The National Energy Centre, Davy Avenue, Knowle Hill, Milton Keynes, MK5 8NG
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