Guidance on the selection and installation of storage cylinders for solar thermal hot water systems

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1 Introduction

Whilst this document is primarily intended for solar thermal systems, much of the guidance is also applicable to other zero and low carbon technologies

At the heart of any successful Solar Thermal system there has to be some form of hot water storage system. This may store domestic hot water ready for use at the tap or store 'primary water' used to produce domestic hot water by means of heat exchange.

When a Solar system is designed for an existing household then of course the particular demands can be directly assessed from the number of persons and their preferences for baths , showers etc.
However in many circumstances this is not possible and we have to fall back on generic guidance from elsewhere particularly with respect to the appropriate regulations.

This general design guidance is relevant for Vented or Unvented hot water storage systems.

As part of the design process the specifier and/or installer should carry out a risk assessment with particular regard to hot water safety issues in terms of scalding, explosion and minimising any risk from water borne organisms such as legionella.

2 Guidance on vessel capacity

For Solar water heating the total storage volume Vt is calculated by adding up the dedicated solar volume Vs defined as the 'volume of water that can only be heated by the solar input' and the additional backup volume Vb which we heat using alternative means such as a boiler or immersion heater.
It should also be noted that some types of system such as those used to provide pre-heat for a combi boiler do not have a 'Vb' in the conventional sense since during periods of low Solar input the water can still be heated by the combi with little or no preheat.

2a Dedicated Solar Volume (Vs) Calculation

Currently the most relevant guidance on dedicated solar volume is in the "Domestic Heating Compliance Guide" to the Part L Building Regulations issued by the

Government in April 2006. Whilst this is specifically targeted at England and Wales the technical guidance is also relevant albeit not necessarily a statutory requirement for Scotland and N Ireland.

Table 31 of the guide currently gives two alternative methods of demonstrating compliance in terms of dedicated storage volume (Vs)

Option 1

There should be at least 25 litres of dedicated solar volume (Vs) per square metre of net panel area. This is generally regarded as the most useful option.

Option 2

The dedicated solar volume (Vs) should be based on 80% of the hot water usage (Vd) as calculated by table 1 of SAP 2005 which relates Vd to the floor area of the dwelling. Except in smaller dwellings of around 50 m^2 floor area and less, this tends to give a smaller value of Vs.

The above guidance meets minimum Building Regulation requirements but where cost, space and other considerations permit then the potential performance can be generally enhanced by increasing the value of Vs. One source of guidance is the EST (CE131) Solar Systems Document where it is suggested that the Vs per square metre of panel area is increased from 25 litres to 35 litres (Option 1); or in the case of Option 2 the volumes are enhanced by a further 25%.

Before increasing the value of Vs consideration should be given to the likely daily requirement for hot water and the implications for the dwell time of water within the cylinder (see Section 7, risk assessment).

Table 1

Typical Guidance for Vs (Dedicated solar volume in litres) based on above

Dwelling Type	**Typical Net Panel Area m^2**	**Minimum Compliance Vs**		**Enhanced Practice Vs**	
		Based on 25 litres/m^2	**Based on SAP**	**Based on 35 litres/m^2**	**Based on SAP**
Small 50 m^2 Floor area	2	50	64	72	80
Medium 75 m^2 Floor area	4	100	80	144	100
Large 110 m^2 Floor area	6	150	95	216	119

2b Assessing Additional Back-up Storage Volume (Vb)

The additional storage volume (Vb) depends on a number of factors but the most important is the likely maximum hot water demand under adverse solar (winter) conditions and the rate at which heat can be added to the top of the cylinder.

Many systems use combined or "twin coil" cylinders where the solar coil is situated at the bottom to preheat the incoming water all year. As solar conditions become more favourable the solar input will increase to the point where the back up boiler or heat source will not fire provided that the controls are set correctly. The following should be regarded as guidance only as individual suppliers may vary in their recommendations according to their specific system details and control strategies.

With the exception of a combi system then it is generally accepted that the absolute minimum additional storage volume for a system heated from a typical 15 to 20 kW boiler is around 90 litres but if a 3kW immersion heater is the only additional heat source and there is likely to be a high hot water demand e.g. two bathrooms, then this volume should be increased.

Total Cylinder Volume   (Vt = Vs + Vb)

On the basis of the information so far it is now worth re-visiting the examples to look at what this may mean in practice.

It should be noted that the capacity ranges shown in Table 2 are for guidance only. Actual hot water requirements vary considerably with number of occupants and their lifestyle. The capacities can generally be rounded up or (slightly) down to the nearest 'standard' available size.

		Table 2 - Typical ranges of capacity
Small	Indirect (12kW)	Vs = 50 Vb = 90 to100 Vt = 140 to 150
	Electric (3 kW)	Vs = 50 Vb = 140 to 150 Vt = 190 to 200
Medium	Indirect (15kW)	Vs = 100 Vb = 100 to 150 Vt = 200 to 250
	Electric (3 kW)	Vs = 100 Vb = 150 to 200 Vt = 250 to 300
Large	Indirect (20kW)	Vs = 150 Vb = 125 to150 Vt = 275 to 300
	Electric (3 kW)	Vs = 150 Vb = 150 to 200 Vt = 300 to 350

3 Guidance on heat exchanger performance

In general terms most Solar systems use some type of differential temperature controller to regulate the transfer of solar heat from the panels to the cylinders.

This is generally via indirect heat transfer either by means of an internal heat exchanger such as a coil or by means of an external heat exchanger usually of the brazed plate to plate variety.

If the external heat exchanger option is required then one side (primary) of the heat exchanger is connected to the pumped solar circuit and water from the storage cylinder is generally pumped through the other (secondary) side from a point near the base of the cylinder to a point just below that at which auxiliary heat can be added.

In order for the heat transfer to occur there must obviously be a positive temperature differential between the panel and the water to be heated. The rate of heat transfer is then dependent on several factors the most significant being the magnitude of the temperature differential, the effectiveness of the heat exchanger and the flow rate through the solar circuit.

One area covered in the Domestic Heating Compliance Guide (Table 31) to the Part L Building Regulations is the relationship between the solar fluid flow rate and the heat exchange area of the cylinder.

The current Part L guidance simply relates minimum heat exchange area to panel area for two ranges of solar fluid flow rate. The guidance makes no reference to the heat exchanger design or material and as such it is a somewhat 'blunt instrument' and really should refer to actual performance as opposed to surface area.

According to Part L then Low flow rate systems (< 0.5litres/minute) need a minimum heat exchanger area of 0.1m^2 per 1m^2 of panel area. For systems with flow rates of 0.5litres/minute or greater the heat exchanger area is doubled.

Clearly such a step stage at 0.5litres/minute does not properly reflect the thermodynamics of heat transfer and a more sophisticated approach is required in order to cope with the various heat exchanger materials and designs available.

Solar panels vary in their output but for typical average UK conditions then we could assume a maximum of around 0.75 kW per m^2 with a daytime average of around say 0.45 kW per m^2.

Typical cylinder heat exchanger coils designed for indirect heating from a boiler with an 80^{o}C flow temperature pumped at around 15 litres a minute will have a heat exchanger rating ranging from 15kW up to 30kW or above. If however these are now connected to a solar system then under most conditions they may be working at much lower temperature differentials and flow rates. It is however possible to use the 'normal' indirect performance as a relative guide to the likely performance under solar conditions.

In reality the factor most affecting the 'efficiency' of heat transfer from the panel to the hot water storage system is often the manner in which the solar controller and pump react in response to an almost infinite variety of possible conditions in relation to the panels and the store.

In addition to stating heat exchanger area, the solar cylinder should carry a label with the heat exchanger power rating stated in kW. It should be noted that this refers to 'normal' boiler primary conditions with a flow temperature of 80^{o}C at 15litres/minute and assumes the heat exchanger power rating for the solar heat exchanger is based on heating the entire contents Vt.

4 System Control Strategies

Having given guidance on cylinder sizing and the performance of the solar heat exchanger we now need to look at some of the other features.

In the UK climate it is not practical to rely solely on solar water heating and there has to be some means of adding heat from an alternative source or sources when required.

Whilst there are all sorts of possibilities the most likely ones will be either by using an electric element (immersion heater) or by means of input from the heating boiler.

In order to maximise potential energy and carbon savings it is important to try to optimise the system design and control strategy to add only the minimum amount of non solar heat that is consistent with maintaining customer satisfaction. This in itself is a subjective area since some eco-conscious end users may be willing to sacrifice the occasional inconvenience of a minimalist ‘top up’ strategy whilst others will demand exactly the same level of convenience as a conventional system.

It is important that the above factors are taken into consideration as part of any risk assessment

If we look at some of the relevant guidance for hot water storage system performance then for a single bathroom property it is generally accepted that after drawing off a bath full of water there should be some left for other purposes and a second bath-full should be available in around 30 minutes. In this context a bath-full of water equates to the thermal equivalent of 100 litres at 40ºC or 60 litres at 60ºC.

If we are limited to a 3kW immersion heater then this amount of water takes over one hour to reheat whilst using say a 15kW boiler (assuming hot water priority) it is only 15 minutes. This is of course reflected in the previous guidance on Vb in the cylinder sizing section.

The general strategy is to configure the solar input such that it is capable of heating the whole of the cylinder to a temperature determined by prevailing conditions of solar gain and hot water demand. In most cases there is a maximum permissible temperature at which the solar input is stopped, this is of course particularly important for unvented systems.

In order to control this solar input the cylinder normally makes provision for one or more temperature sensors. Generally the solar sensor is sited at a position where it senses temperature rise due to solar input but is below the level at which auxiliary heat input occurs.

In the case of the auxiliary input the sensor is higher in the cylinder and ensures that temperatures at or above the sensor point are maintained by the immersion heater or boiler input.

5 Insulation

It is recommended that solar cylinders are insulated such that their maximum standing heat loss does not exceed the value as calculated by the formula below:-

$Q = 1.28 (0.2 + 0.051xVt^{2/3})$

Q = heat loss in kWh/day
Vt = total cylinder volume

It should be noted that for cylinders the standing heat loss is measured with a stored water temperature of 65°C and for thermal stores 75°C.

6 Labelling

In order to comply with Part L Building Regulations the cylinder must be labelled with the following information.

- Cylinder type
- Capacity
- Standing Heat loss
- Heat Exchanger performance – (from boiler)

For solar cylinders this list should be extended as follows.

- Cylinder type
- Total Capacity Vt
- Dedicated Solar Volume Vs
- Standing Heat loss
- Auxiliary Heat Exchanger performance – (indirect only)
- Solar coil heat exchanger area (if applicable)
- Solar Heat Exchanger performance

7 Risk Assessment

When planning to install or make modifications to a Solar (or indeed any) hot water storage system, a risk assessment should be carried out including the following factors.

7.1 Scalding Risk
Hot water can of course give rise to scalding and the young and elderly are most at risk.

In order to maximise the benefits of Solar input many control systems allow the cylinder contents to go to much higher temperatures than the 'normal' 60°C and we would strongly recommend the use of a thermostatic blender valve to prevent high temperatures reaching the hot water outlets. Ideally the whole of the hot water system could be protected by a thermostatic mixer at the outlet from the hot water system. The area of greatest risk is at the bath tap and it is likely that the forthcoming revision of the Part G Building Regulations will advise that thermostatic control should be fitted to prevent an outlet temperature in excess of 48°C.

A further risk is posed by the cold feed cisterns feeding vented cylinders, as under fault conditions these can receive high temperature water from an overheated cylinder. The cistern is normally of a plastics material and is capable of coping with high temperature water provided it is properly supported over the entire area of its base. If there any doubts about the integrity of the cistern or its support then the cistern and/or its support should be replaced.

In addition any immersion heaters fitted to the cylinder should have non auto resetting energy cut outs. It should be noted that the fitting of a Solar Thermal system might present an ideal opportunity to upgrade to a mains pressure unvented system or thermal store.

7.2 Explosion Risk

It should be noted that for vented cylinders the most important feature is the presence of a clear open vent pipe from the top of the cylinder to a safe discharge point (normally into the cold feed cistern) .

In order to comply with UK regulations all unvented cylinders must comply with the Part G Building Regulations which call for third party certification to ensure that the relevant safety controls are fitted.

The most important single feature is the temperature relief and at the planning stage consideration must be given to the provision of suitable discharge pipework.

7.3 Legionella

It should be understood that Legionella bacteria are always present in water systems.

If these bacteria are given favourable breeding conditions then their levels can become unacceptable.

Certain factors are known to increase the potential for breeding whilst others reduce or virtually eliminate the risk. In Germany for instance the risk is considered minimal in tanks of less than 400 litres capacity. The highest risk areas are large scale hot water systems such as hotels and hospitals where parts of the systems may be static for long periods but the problem can also occur in domestic dwellings.

In general terms the preferred breeding temperature range of legionella is from 20ºC to 50ºC. Once temperatures exceed 50ºC the bacteria start to die off. This is almost instantaneous at 70ºC or above but, for instance, over 90% of the most common strain of legionella are killed in 2 minutes at 60ºC and in around one hour at 55ºC.

It should also be realised that even in non-solar systems there is no guarantee that stored hot water will remain above the critical temperatures for sufficient time to kill of any legionella.

The consensus from elsewhere in the world where solar is well established is that any additional risk from domestic solar systems is minimal and can be further controlled by good practice to reduce the potential for the growth of legionella and/or adopt strategies to periodically kill off any legionella by means of thermal disinfection or other means.

7.3.1 Thermal Disinfection

The most popular control strategy as widely adopted elsewhere in the world is the so called 'hot top' where the top of the cylinder as defined by Vb is regularly brought up around 60^{o}C for a period sufficient to neutralise the bacteria.

If this is the chosen method then the system and its controls should be designed such that the likelihood is that any water reaching the taps will have been pasteurised by experiencing a suitable time/temperature regime at the top of the cylinder in the volume defined as Vb. One generally recognised regime is one hour at 60^{o}C on a daily basis and this will generally be achieved using the values of Vb shown in Table 2.

In systems where it is not possible to adopt this 'hot top' strategy another option is to pasteurise the whole of the cylinder contents Vt by heating to 60^{o}C or above on a regular basis (perhaps once or twice a week).

7.3.2 System Sizing and Dwell time

One very effective means of controlling the growth of legionella is by reducing the 'dwell' time within a system. This is best explained by way of example.

In a typical family household the daily throughput of hot water may be in the region of 120 litres. It can easily be seen that given a Vb of a similar or greater capacity then the 'hot top' strategy will ensure that under normal circumstances the water will be pasteurised on a daily basis and it is unlikely that any water will remain static anywhere in the cylinder for more than two days. It is for this reason that whilst over sizing of the dedicated solar volume Vs may give some efficiency benefits the likely effect on dwell time must also be factored in and unless there is a known high hot water demand the risk of contamination may be increased.

On a similar basis the use of thermal stores where the amount of domestic hot water in the heat exchanger is minimal then the short dwell time will significantly reduce the risk.

7.3.3 System Cleanliness

The best form of control is of course not to let the bacteria breed in the first place.

If dealing with an existing vented system fed by a cold feed cistern then the first area to look at is the feed cistern itself.

The cistern should be one of the 'byelaw 30' variety, with a close fitting lid and any breather or discharge pipe incorporating a protective mesh. If there are any doubts about the integrity and cleanliness of the cistern then it should be replaced.

Whilst in this area a check should also be made to ensure that the cistern is adequately insulated. Whilst such insulation may be primarily for frost protection it also helps avoid excessive water temperatures during the summer period.

The second area to consider is the water pipe-work with particular reference to undesirable features such as dead legs or instances where hot and cold pipes run in close proximity. Again if in doubt then replace the 'offending' sections and consider disinfection of the system as part of the commissioning procedure.

In most homes the areas at most risk are shower outlets as legionella is transmitted as an aerosol. Particular attention should be given to the pipes feeding the shower including the condition and positioning of any flexible hoses so that they are as far as possible self draining and not likely to be immersed in warm bath water.

7.3.4 Consumer Awareness and instructions.
Bearing in mind that legionella may be present in the incoming water supply, the risk of infection can be minimised by simple actions based on consumer awareness. This involves ensuring that the thermostat or control setting for the temperature of Vb is at 60ºC and that programmers are set correctly to activate the backup heat source as required.

The highest risk is probably on return from a winter holiday in a period of little solar gain where all or part of the hot water system has been sitting at the preferred breeding temperature for perhaps a week or two. The consumer should be advised that it would be good practice to run off some water on their return from holidays in order to clear the pipes of any static water then to make sure that the top of cylinder has been at temperature for an hour or two before showering.

If a lower immersion heater is fitted then it might also be appropriate to heat up the entire contents to 60ºC.

7.3.5 Risk Assessment Check list

- Check cold feed cistern (if vented) for size, support, integrity and cleanliness.
- Is total or bath tap thermostatic control required?
- Check vent pipe (vented) or discharge pipe (unvented)
- Check sizing of storage vessel against likely daily throughput.
- Check that sufficient backup heat input relative to Vb is available
- Check pipework for dead legs, hot pipes in close proximity etc.
- Check shower fittings, especially flexible hoses.

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