

**Calculation Method for evaluating Solar Assisted Heat Pump
Systems in SAP 2009**

15 July 2013

1 Introduction

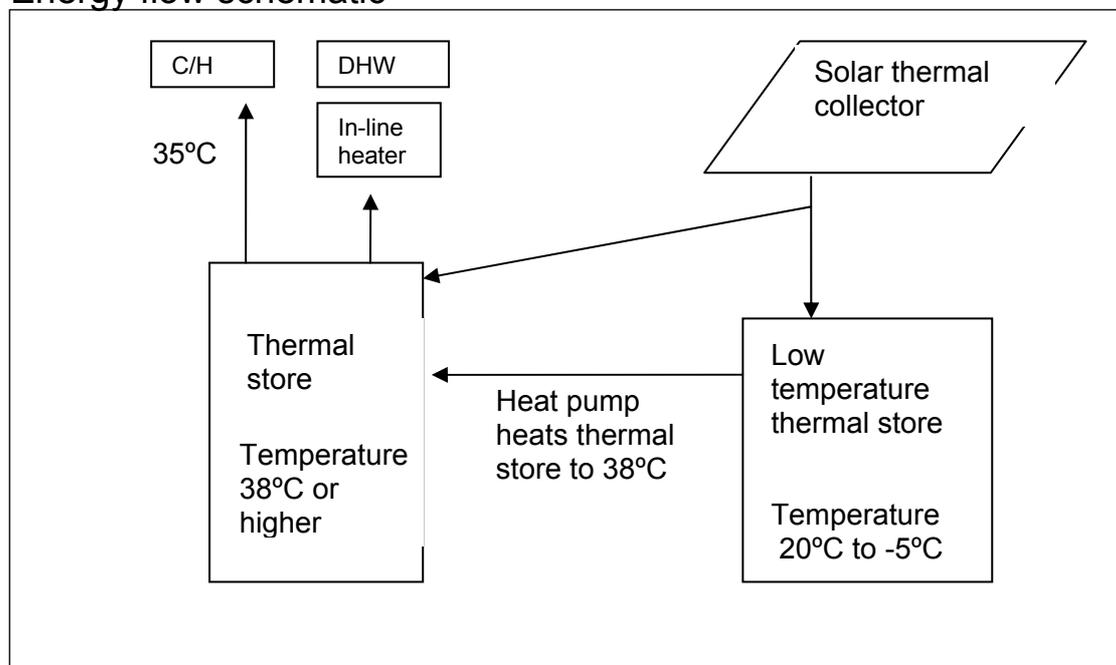
This document describes how Solar Assisted Heat Pump Systems are recognised in the National Calculation Method for Energy Rating of Dwellings, known as SAP 2009.

Below is a simplified energy flow diagram of a Solar Assisted Heat Pump System, which includes the following principal components:

- Solar thermal heat collector/ambient heat absorber
- Water-to-water heat pump
- Thermal store
- Low temperature thermal store

Note: the diagram only shows the main energy flows and not actual connections.

Energy flow schematic



Solar thermal collectors embedded in roof tiles capture insolation on warm sunny days, whilst absorbing ambient heat from surrounding air at night and during overcast periods.

Captured solar energy is fed to:

- a) the thermal store, when the solar-heated water is warm enough, or
- b) the low temperature thermal store otherwise

Heat absorbed by the collector at night or on overcast days from the environment is fed to the low temperature thermal store.

A water-to-water heat pump transfers heat from the low temperature thermal store to the thermal store when requested by the control system.

Domestic space heating and hot water services are provided by pumping Primary Water from the thermal store to two separate plate heat exchangers, where heat is transferred to the domestic space heating system or to a separate mains pressure hot water system that has a supplementary direct electric inline heater.

For the purposes of analysis in SAP, the operation of the system has been divided into four modes.

Mode 1 (day time warm and sunny)

Defined as the daylight hours (hours between sunrise and sunset) when the air temperature exceeds 15°C and horizontal direct and diffuse insolation exceeds 10W/m². In this Mode:

- Solar energy is captured and delivered to the thermal store to offset hot water heating load. Any shortfall is met by the electric inline heater.
- The heat pump does not operate.

Mode 2 (day time cool and sunny)

Defined as the daylight hours when the air temperature is 15°C or below and horizontal direct and diffuse insolation exceeds 10W/m². In this Mode:

- Solar energy is captured and delivered to the low temperature thermal store
- The heat pump upgrades heat from the low temperature thermal store to the thermal store. The heat source for the system is the outside air and solar energy combined; an average source temperature of 10°C is assumed. The sink temperature is 38°C (or suitable set-point defined by Manufacturer).
- The thermal store supplies heat to the hot water and space heating systems. Any shortfall in water heating load and space heating load is met by separate direct-electric inline heaters.

Mode 3 (day time cool and overcast)

Defined as the daylight hours when the air temperature is 15°C or below and direct and diffuse insolation is 10W/m² or below. In this Mode:

- The solar collector absorbs ambient heat and delivers it to the low temperature thermal store.
- The heat pump upgrades heat from the low temperature thermal store to the thermal store. The heat source for the system is the outside air; an average source temperature of 4.5°C is assumed. The system operates similarly to an Air Source Heat pump in this mode. The sink temperature is 38°C (or suitable set-point defined by Manufacturer).
- The thermal store supplies heat to the hot water and space heating systems. Any shortfall in water heating load and space heating load is met by separate direct-electric inline heaters.

Mode 4 (night-time)

Defined as the hours when not in mode 1, 2 or 3. In this Mode:

- The solar collector absorbs ambient heat and delivers it to the low temperature thermal store.
- The heat pump upgrades heat from the low temperature thermal store to the thermal store. The heat source for the system is the outside air; the low temperature thermal store is assumed to be 5°C below the outside air temperature giving an average source temperature of -1.2°C. The system operates similarly to an Air Source Heat pump in this mode. The sink temperature is 38°C (or suitable set-point defined by Manufacturer).
- The thermal store supplies heat to the hot water and space heating systems. Any shortfall in water heating load and space heating load is met by separate direct-electric inline heaters.

Any shortfall in space heating is determined by the capacity of the heat pump or rate of heat transferred to the low temperature thermal store, whichever is the smallest. The thermal store is assumed to supply heat for space heating first, with any remaining heat supplied to the domestic hot water service.

2 Basis of the method

The basis of the Solar Assisted Heat Pump calculation method is to analyse the Mode 1 operation within a separate supplementary calculation procedure (Appendix Q workbook). The other modes of operation (Modes 2 – 4) are modelled as a standard heat pump, see SAP 2009 Appendix N, but with modified average source and sink temperatures as noted above and in accordance with EN15316. The Plant Size Ratio (PSR) range is also extended to 5.0, where the Product Characteristics Database (PCDB) records values at: 0.2, 0.6, 1.0, 2.0, 3.0, 4.0 and 5.0.

The additional heat losses associated with Solar Assisted Heat Pump systems in comparison to standard types (i.e. air, ground or water source) are also modelled within the supplementary calculation procedure (Appendix Q) for all operating modes.

2.1 Mode 1

The supplementary calculation procedure (Appendix Q) calculates the direct reduction in water heating due to captured solar energy when the air temperature exceeds 15°C and direct and diffuse solar insolation exceeds 10W/m².

To simplify the calculation process (Appendix Q) for Mode 1 operation, a reference system was defined to which the addition or reduction of energy consumption is applied within SAP software. The specification for this reference system is below:

- Space heating is provided by the defined Solar Assisted Heat Pump using performance data recorded in the Product Characteristics Database (PCDB).
- Water heating is provided by a 160 litre cylinder with integral electric immersion and a manufacturer's declared heat loss of 2.21 kWh/day (when cylinder is 45K above the test laboratory air temperature).
- The cylinder is installed outside the heated space.
- No solar water heating system

In SAP 2009, the heat loss from an ordinary hot water cylinder is an annual calculation defined as:

- Number of days in a year x daily heat loss for a cylinder with a standard 45K above its surrounding x temperature factor.

The temperature factor (e.g. 0.6) accounts for the cylinder, when installed in the dwelling, being at a lower temperature than the standard test criteria.

The above SAP assumptions are invalid for the thermal store of a Solar Assisted Heat Pump, since being installed outside and partially submerged underground its heat losses will vary monthly. The thermal store heat loss calculations are amended to monthly calculations and account for operation within all operating modes - see section 3.1.1. These calculations are undertaken within a separate supplementary calculation procedure (Appendix Q workbook).

Heat losses for the external pipework connected to the thermal store for both space heating and hot water systems are also accounted for by the monthly calculation in section 3.1.1. These calculations are also undertaken within a separate supplementary calculation procedure (Appendix Q workbook).

The low temperature store is not used in mode 1 and therefore excluded from the Mode 1 calculation procedure.

2.1.1 SAP 2009 - Solar water heating calculations

The contribution of captured solar energy towards hot water heating is calculated in accordance with SAP 2009 Appendix H, extract below:

The solar contribution to domestic hot water is given by:

$$Q_s = S \times Z_{panel} \times A_{ap} \times \eta_0 \times UF \times f_1 \times f_2$$

Where:

Q_s = solar input, kWh/year

S = total solar radiation on collector, kWh/m²/year

Z_{panel} = overshadowing factor for the solar panel

A_{ap} = aperture area of collector, m²

η_0 = zero-loss collector efficiency

UF = utilisation factor

a_1 = linear heat loss coefficient of collector, W/m²K

$$f_1 = \text{collector performance factor} = \begin{cases} 0.97 - 0.0367 (a_1/\eta_0) + 0.0006 (a_1/\eta_0)^2 & \text{if } a_1/\eta_0 < 20 \\ 0.693 - 0.0108 \times a_1/\eta_0 & \text{if } a_1/\eta_0 \geq 20 \end{cases}$$

V_{eff} = effective solar volume, litres

V_d = daily hot water demand, litres

$$f_2 = \text{solar storage volume factor} = 1.0 + 0.2 \ln(V_{eff}/V_d) \text{ subject to } f(V_{eff}/V_d) \leq 1.0$$

Note. The overall performance of solar water systems depends on how the hot water system is used, e.g. daily draw-off patterns and the use of other water heating devices such as a boiler or an immersion. The procedure described here is not suitable for detailed design in a particular case. It is intended to give a representative value of the solar contribution to domestic water heating over a range of users.

Insolation is determined from tables that account for the solar collector angle of tilt and orientation. The zero heat loss collector efficiency and linear heat loss factor are tested according to EN12975-2 (*Thermal solar systems and components - Solar collectors - Part 2: Test methods*)

The solar collector performance factor is a function of the collector's heat loss and zero heat loss efficiency.

The solar storage volume factor is calculated from the ratio of the volume of solar store and the daily water usage. When the solar storage volume is greater than the daily hot-water usage the factor is 1.

The utilisation factor accounts for the magnitude of captured solar energy compared to the energy required to heat the hot water. That is, high levels of captured solar energy cannot always be utilised.

2.1.2 Application for Solar Assisted Heat Pump Systems

The captured solar energy is only applicable to Mode 1 operation for the calculation procedure. Therefore, the SAP Appendix H variable (S) 'total solar radiation on collector' is multiplied by the fraction of incident solar energy in mode 1 (see Table 2, Section 3.1.2).

In SAP the heat losses from a solar hot water cylinder are not explicitly modelled and are therefore excluded from the calculation of the utilisation factor.

The heat loss from the Solar Assisted Heat Pump system thermal store and distribution pipework is substantially higher than typical losses from solar thermal systems and is therefore included in the supplementary procedure. These losses should strictly also be included in the solar utilisation factor calculation. However, including this would introduce a complex iterative process.

To avoid the requirement for an iterative process, the usefulness of solar energy is limited to the hot water energy requirement plus the thermal store and distribution pipe heat loss. The solar collector performance factor (f1) and solar storage volume factor calculations (f2) are unchanged.

2.2 Mode 2, 3 and 4

The operating modes 2, 3 and 4 are analysed within SAP software utilising the heat pump data record held within the Product Characteristics Database (PCDB). The data forming the record is calculated according to EN15316 using laboratory measurements¹ and hourly climate data. EN15316 determines the Seasonal Performance Factor (SPF) and any supplementary heating required as a function of the plant size ratio.

Hourly weather data containing air temperatures and direct and diffuse horizontal insolation were sourced from a standard reference climate year for Leeds². It is composed of typical monthly data selected from ten years of data.

The EN15316 calculation procedure only accounts for solar energy input during cold and bright periods (Mode 2). Hourly weather data was used to calculate the monthly fraction of captured solar energy during cold periods (see table 2), when direct and diffuse insolation was greater than 10W/m² and 'cold' was defined as 15°C or lower. The fraction of captured solar energy during cold periods is multiplied by the monthly insolation values within Appendix H of SAP 2009 and transferred to the EN15316 calculation procedure. Specified insolation values are for a south facing panel with little or no over shading.

The sensitivity of heat pump Seasonal Performance Factor to minor variations in solar collector area, orientation and tilt was found to be insignificant when assessed by the EN15316 calculation procedure, particularly given the large area of solar collector. For example, a tolerance of 19-25 m² is therefore permitted for a nominal tested area of 20.11 m². Additionally, hydraulically separated multiples of collector areas are permitted in order to increase the effective heat pump output, whilst simultaneously capturing more solar energy. In this example, the nominal defined collector area sizes are therefore:

- a) 19 to 25m²
- b) 38 to 50m²
- c) 57 to 75m²

Note: It is critical that collector areas are hydraulically separated from any additional areas, in this example 19-25m², since this calculation method assumes the solar collectors will not stall.

¹ See: 'SAP 2009 Calculation Methodology for electrically driven heat pumps'

² The test reference year is composed of monthly data from different years (e.g. January from year x, February from x-3, March from year x+5) that were considered as a typical month from the years available and is primarily designed for complex dynamic building computer models, see Ref 1

3 Procedure

The following are the required data items for each Solar Assisted Heat Pump system to be recognised within SAP 2009³:

- a) Manufacturer
- b) Brand
- c) Model Name
- d) Model Qualifier
- e) Thermal store volume
- f) The heat loss of thermal store above ground at a standardised 45K temperature difference to ambient external environment. Based on measurements or independent third-party simulation.
- g) The heat loss of thermal store below ground at a standardised 45K temperature difference to surrounding ground environment. Based on measurements or independent third-party simulation.
- h) The heat loss for the pipes connecting the thermal store to the dwelling at a standardised 45K temperature difference to ambient external environment. This is calculated using typical installation pipe lengths, diameter and insulation levels agreed with the manufacturer.
- i) Solar collector heat loss $W/m^2/K$ from UKAS or equivalent third party test measurements to EN12975-2:2006
- j) Solar collector efficiency at zero heat loss from UKAS or equivalent third party test measurements to EN12975-2:2006
- k) Area of solar collector (m^2)
- l) Solar collector pump power (Watts)

The user selects the collector brand and model and enters the details of the dwelling and heating system into the supplementary calculation (Appendix Q) workbook. The user must also enter the following parameters into SAP calculation software:

- a) Space heating provided by the recognised Solar Assisted Heat Pump System from the Product Characteristics Database (PCDB) record according to brand, model and model qualifier.
- b) Water heating is provided by a 160 litre cylinder with integral electric immersion and a manufacturer's declared heat loss of 2.21 kWh/day.
- c) The hot water cylinder is specified as 'outside the heated space'.

The calculation procedure calculates the decrease or increase in energy consumption relative to the above scenario as detailed in section 3.1.

3.1 Calculations

The calculation procedure determines the difference in energy required for hot water heating between that required by the Solar Assisted Heat Pump System and that required by the reference system (see Section 2.1 for details). This is undertaken in the following sequence:

1. The energy required for hot water heating for the Solar Assisted Heat Pump System is calculated in accordance with sections 3.1.1 to 3.1.5.
2. The energy consumption for the reference system is calculated in accordance with section 3.1.6.

³ Parameters (e) – (l) are recorded within the Appendix Q workbook (supplementary calculation procedure), whilst all others are recorded within the workbook and the Product Characteristics Database (PCDB).

3. The overall energy performance of the Solar Assisted Heat Pump is compared to the reference system and is calculated in accordance with section 3.1.7.

3.1.1 Thermal store heat losses and distribution pipe losses

For each month calculate the heat loss from the thermal store according to (1).

$$Q_{store,m} = N_d \times \frac{Q_{air,45K} \times (T_{store,m} - T_{air,m}) + Q_{grd,45K} \times (T_{store,m} - T_{ground,m})}{45} \quad (1)$$

where:

N_d is the number of days in the month.

$Q_{air,45K}$ and $Q_{grd,45K}$ are the daily heat losses for the section of thermal store above and below ground respectively, standardised to a 45K temperature rise above its surroundings. These are supplied by the manufacturer either from physical tests or from a simulation conducted by an independent third-party.

T_{store} is the monthly average temperature of the thermal store (i.e. the manufacturer's defined set point temperature).

$T_{air,m}$ is the monthly air temperature used in SAP 2009

$T_{ground,m}$ is the monthly ground temperature set to the average yearly air temperature for each month

Note: In mode 1 the temperature of the thermal store will be higher than the set-point (defined by manufacturer) due to the captured solar energy heating the thermal store directly and thereby increasing its standing heat loss above that calculated in (1). The beneficial captured solar gains are limited to the maximum hot water energy required plus the thermal store heat loss and distribution pipe heat loss, instead of using the solar utilisation factor as explained in part 3.3.3. Therefore, if a higher standing heat loss than that at the defined set-point were calculated, it would merely increase solar energy contribution by the same amount, with no net change in the overall energy consumption.

For each month calculate the heat loss connecting the external thermal store to the hot water heating and space heating distribution systems:

$$Q_{pp,m} = N_d \times \frac{Q_{pp,air,45K} \times (T_{store,m} - T_{air,m}) + Q_{pp,grd,45K} \times (T_{store,m} - T_{ground,m})}{45} \quad (2)$$

where:

$Q_{pp,air}$ and $Q_{pp,grd}$ is the pipe heat loss to air and ground standardised to a 45K temperature rise above its surroundings.

Standardised pipe heat losses agreed with the manufacturer are held within the supplementary calculation (Appendix Q) workbook. A small range of options are assigned based on typical pipe diameters, lengths and insulation levels between the thermal store and the dwelling. These options account for heat losses during space heating and hot water heating operation with four installation options provided in the table below.

Pipe exposure and insulation	Standardised heat loss kWh/day	
	Air	Ground
2.5m or less of insulated pipe, mostly above ground	-	x.xx
2.5m or less of insulated pipe, mostly buried	x.xx	-
More than 2.5m but less than 5m of insulated pipe, mostly buried	-	x.xx
More than 2.5m but less than 5m of insulated pipe, mostly above ground	x.xx	-

Table 1 - Pipe heat loss data required

The heat losses in Table 1 must use the following specifications:

- 2.5m or 5m refers to a single pipe length (e.g. the flow or return), but the total heat loss is doubled in the supplementary calculation (Appendix Q) workbook to account for both.
- 'Standardised' refers to a temperature difference of 45K between the pipe and the surrounding environment.
- Pipe inside diameter is Xmm with insulation thickness of Xmm of thermal conductivity (λ value) of X W/mK. The values denoted as 'X' are defined by the manufacturer during the SAP Product Recognition stage and recorded in the supplementary calculation (Appendix Q) workbook.
- The insulated pipe conduction heat loss (i.e. excluding the heat surface coefficient) is calculated from: $2\pi \times l \times \lambda \times \ln(r_2 / r_1)$, where 'l' is the total pipe length (5 or 10m) and 'r₂' and 'r₁' is the inside and outside radius of the insulated pipe.
- A 0.13 m²K/W surface heat transfer resistance is applied to the insulated external pipe surface area above ground, whilst no surface resistance is applied to the pipe installed below ground.
- The heat loss to the air over a 24 hour period (kWh) for a temperature difference of 45K between the pipe and the surrounding environment is:

$$Q_{pp,air} = \frac{45 \times 0.024}{\frac{1}{2\pi \times l \times \lambda \times \ln(r_2 / r_1)} + \frac{0.13}{2\pi r_2 l}}$$

- The heat loss to the ground over a 24 hour period (kWh) for a temperature difference of 45K between the pipe and the surrounding environment is:

$$Q_{pp,grd} = 45 \times 0.024 \times 2\pi \times l \times \lambda \times \ln(r_2 / r_1)$$

3.1.2 Solar water heating contribution

Calculate the monthly solar heating contribution to water heating as:

$$Q_{S,m} = Q_s \times f_m \times N_d \times H_s \times Z_{panel} \times A_{ap} \times \eta_0 \times f(a_1 / \eta_0) \quad (3)$$

Q_s	is the incident annual radiation on collector, kWh/m ² /year (see Table H2, SAP 2009)
f_m	is the monthly to annual ratio (Table H3, SAP 2009)
N_d	is the number of days in the month
H_s	is the monthly fraction for warm and sunny days (see Table 2 below)
Z_{panel}	is the over shading factor for the solar collector
A_{ap}	is the aperture area of collector, m ²
η_0	is the zero-loss collector efficiency
a_1	is the linear heat loss coefficient of collector, W/m ² K
$f(a_1 / \eta_0)$	is collector performance factor defined as:

$$f(a_1 / \eta_0) = 0.97 - 0.0367 (a_1 / \eta_0) + 0.0006 (a_1 / \eta_0)^2 \quad \text{if } (a_1 / \eta_0) < 20$$

$$f(a_1 / \eta_0) = 0.693 - 0.0108 (a_1 / \eta_0) \quad \text{if } (a_1 / \eta_0) \geq 20$$

Limit the monthly solar contribution to:

$$Q_{mxS,m} = Q_{store,m} + Q_{hw,m} \quad (4)$$

where:

$Q_{hw,m}$ is the monthly hot water demand ([45_m] in SAP 2009 Worksheet).

$Q_{store,m}$ is the monthly heat loss from the store calculated from equation (1)

Note: Since the thermal store's heat loss can be recouped by the solar contribution (for Mode 1), in theory the utilisation factor should include the large thermal store and distribution pipe heat losses. However, introducing the heat losses into the solar utilisation factor calculation would mean introducing an iterative calculation which is not practical in SAP. Instead, the usefulness of the captured solar energy is limited to the hot water energy requirement plus the thermal store's associated standing heat loss (i.e. the thermal store and distribution pipework heat losses). This approach is reasonable given that the SAP solar utilisation factor approach was devised for normal sized solar water heating system and Solar Assisted Heat Pump Systems have very large thermal stores and solar collector areas.

	Captured solar energy fraction delivered to thermal store H_s	Captured solar energy fraction delivered to low temperature thermal store
January	0.0%	98.4%
February	0.0%	99.3%
March	5.4%	94.4%
April	8.2%	91.6%
May	41.1%	58.8%
June	46.6%	53.3%
July	85.1%	14.7%
August	77.0%	22.9%
September	56.7%	43.1%
October	7.8%	91.7%
November	1.5%	97.3%
December	2.3%	94.7%

Table 2 - Fraction of captured solar energy delivered to thermal store and low temperature thermal store

The daily captured solar energy delivered to the thermal store is the fraction delivered in daylight hours when the air temperature exceeds 15°C and the horizontal direct and diffuse insolation is greater than 10W/m².

3.1.3 Hot water uplift

The thermal store is heated by the heat pump to a temperature set point defined by the manufacturer (i.e. 38°C). On warm and sunny days captured solar energy will increase the temperature further. However, the temperature of the thermal store may not be sufficient to satisfy the required domestic hot water temperature, even during warm and sunny periods. The nominal average hot water delivery temperature in SAP 2009 is approximately 52°C but varies monthly. A direct electric inline heater is provided to supplement hot water heating and its operation is analysed within the Appendix Q procedure. This is calculated as the difference (shortfall) between the maximum delivery temperature delivered by the thermal store and the SAP monthly hot water temperature.

This section estimates any shortfall in the water heating that is met by the electric inline heater and is the amount of energy required to heat hot water to the desired temperature (e.g. 52°C⁴) above the thermal store temperature.

First, the monthly thermal store temperature rise due to solar heat gains is estimated from the energy balance and the heat capacity of the thermal store (i.e. the volume multiplied by the specific heat capacity of water). This is the net heat gain resulting from the temperature rise due to the solar water heating contribution, less any thermal store and distribution pipe heat losses, divided by the heat capacity. This will give the accumulated temperature rise at the end of the month. Dividing by the number of days in the month will give the expected average temperature rise at the end of each day. The thermal store temperature will accumulate each day, which will increase the thermal store's heat losses, until such time as the heat losses equal the captured solar energy.

⁴ In SAP 2009 the temperature of the delivered hot water varies monthly and is calculated by adding the monthly values of SAP Table 1d and SAP Table G2.

Calculate the average daily temperature rise due to solar heat gains for each month thus:

$$\Delta T_{st+,m} = [(Q_{s,m} - Q_{hw,m} - Q_{st+,m} - Q_{pp+,m})] \times 3600 / (4.19 \times V_{hs} \times N_d) \quad (5)$$

$Q_{s,m}$ is the monthly solar heating contribution calculated in (3)

$Q_{hw,m}$ is the monthly energy delivered to the domestic hot water (SAP box 45 + 46)

$Q_{st+,m}$ is the monthly heat loss from the thermal store at the required monthly hot water supply temperature ($T_{hwd,m}$). This is calculated by substituting $T_{hwd,m}$ in place of $T_{store,m}$ in equation 1.

$Q_{pp+,m}$ is the primary pipe heat loss assuming the thermal store temperature is $T_{hwd,m}$ and is estimated from equation (2) by replacing $T_{store,m}$ with $T_{hwd,m}$.

V_{hs} is the volume of the thermal store

N_d is the number of days per month

4.19 is the specific heat capacity of water in kJ/litres/K

3600 is a multiplier that converts from kWh to kJ

Determine the fraction of days per month ($P_{in(iso),m}$), when considered in isolation, where the supplementary electric inline heater is required to raise the hot water temperature (from heat supplied by the thermal store at the defined temperature set point) to the desired hot water temperature according to (6):

$$\text{If } \Delta T_{st+,m} > 0 \quad P_{in(iso),m} = \frac{(T_{hwd,m} - T_{store})}{N_d \times \Delta T_{st+,m}} \quad (6)$$

$$\text{If } \Delta T_{st+,m} = 0 \text{ then } P_{in(iso),m} = 1$$

If the result of (6) is greater than 1 reset to 1.

$T_{store,m}$ is the temperature the thermal store reaches from use of the heat pump alone (i.e. the set-point temperature, defined by Manufacturer)

$T_{hwd,m}$ is the average temperature of the delivered hot water temperature which varies monthly (sum of SAP Table 1d and SAP table G2).

Equation (6) considers months in isolation and not consecutively. When considered consecutively the thermal store may have reached the required hot water temperature in the previous month (i.e. the summer months when operating in Mode 1, where the set-point temperature $T_{store,m}$ may be exceeded) and would remain so until the required energy for hot water services exceeds the captured solar energy

(less heat losses). To determine the fraction of days per month, when considering the months consecutively, the results of equation (6) are applied to each month as noted below:

- In calendar order, note the first month where the fraction of days (where supplementary hot water heating is required) is less than 1.
- In reverse calendar order, starting from December note the first month where the fraction of days is less than 1.
- For the months between (a) and (b), but not months (a) or (b), set the fraction of days to zero. The fractions of days for all other months are unaltered.

The fraction of days per month where supplementary hot water heating is required when considered consecutively is $p_{in,m}$. Calculate the supplementary energy required for each month, if any, by the electric inline heater:

$$Q_{up,m} = \left[\frac{p_{in,m} \times Q_{hw,m} \times (T_{hwd,m} - T_{store})}{(T_{hwd,m} - T_{cold,m})} \right] \times [1 - C.o.P_{hw}] \quad (7)$$

$Q_{hw,m}$ is the monthly energy delivered in the hot water (SAP box 45 + 46)

$C.o.P_{hw}$ is the heat pump coefficient of performance when delivering heat from the low temperature thermal store to the thermal store.

3.1.4 Circulator energy consumption

Calculate the annual electricity consumption of the circulation pump during mode 1 as:

$$Q_{circ} = h_m \times \text{circulator power(W)} / 1000 \quad (8)$$

$h_m = 1248\text{hrs}$, which is the number of hours per year that the system operates in Mode 1. This is defined as the number of hours where the air temperature exceeds 15 °C and the direct and diffuse insolation exceeds 10 W/m².

3.1.5 Sum the individual contributions

Using the results of (1) to (8) calculate the annual water heating energy as below, where sigma refers to the monthly summation over the year.

$$Q_{hw,system} = Q_{circ} + Q_{uplift,m} + \sum_{m=1}^{m=12} [(Q_{pp,m} + Q_{store,m} + Q_{hw,m} - Q_{s,m}) / C.o.P_{hw}] \quad (9)$$

The $C.o.P_{hw}$ is taken to be the same value calculated in EN15316 for space heating operation. This is a reasonable assumption since it represents the Coefficient of Performance (CoP) of heat delivery to the thermal store, which provides both space heating and hot water heating services.

3.1.6 Water heating consumption of the reference system

The energy consumption of the reference system is calculated using SAP conventions within SAP software. The reference hot water system is an electric immersion within a 160 litre tank installed outside the heated space. The tank has a manufacturer's declared heat loss of 2.21 kWh/day.

$$Q_{hw,ref} = \sum_{m=1}^{m=12} [(Q_{refstore,d} \times 0.6 \times N_d) + Q_{hw,m}] \quad (8)$$

where:

$Q_{refstore,d}$ is standardised daily heat loss of 2.21 kWh/day

0.6 is the temperature factor (See table 2b of SAP 2009)

N_d is the number of days per month

$Q_{hw,m}$ is the monthly energy delivered in the hot water (boxes (45)m of SAP worksheet)

3.1.7 Overall energy savings

The overall energy savings (or penalty) calculated by the supplementary calculation (Appendix Q) workbook is:

$$\text{Energy saving (or penalty if negative)} = Q_{hw,ref} - Q_{hw,system} \quad (9)$$

4 References

1. Standard reference year weather data for Leeds from *CIBSE Guide J: Weather, Solar and Illuminance Data*.
2. The Government's Standard Assessment Procedure for Energy Rating of Dwellings 2009 edition incorporating RdSAP 2009, March 2010, BRE

Appendix

This appendix lists the hours of operation of mode (Table A1) and the table data used in the EN15316 calculation procedure (Table A2 and A3).

Mode 1 – Hours when air temperature exceeds 15°C and direct and diffuse insolation exceeds 10W/m²

Mode 2 – Hours when air temperature is 15°C or below and direct and diffuse insolation exceeds 10W/m²

Mode 3 – Hours of daylight when air temperature is 15°C or below and direct and diffuse insolation is 10W/m² or below

Mode 4 – Hours of darkness or when not in Mode 1, Mode 2 or Mode 3.

	Mode 1	Mode 2	Mode 3	Mode 4
	hours	hours	hours	hours
January	0	226	32	486
February	0	256	30	386
March	12	339	3	390
April	30	374	4	312
May	137	338	9	260
June	194	286	30	210
July	373	116	38	217
August	291	149	25	279
September	188	175	27	330
October	16	290	38	400
November	3	235	34	448
December	4	186	31	523

Table A1 - Hours operation by mode

	Solar energy transmitted In kWh per month
	Mode 2
January	221.11
February	362.96
March	557.47
April	740.04
May	596.16
June	555.89
July	153.27
August	204.01
September	289.25
October	435.62
November	259.87
December	176.40

Table A2 - Solar energy transmitted to collector for EN15316 calculations

Note - Table A2 uses the following assumptions:

Solar collector measured efficiency at zero heat loss of 73%

Solar collector heat loss coefficient of 15.11 W/m²/K

Solar collector on 30° slope and south facing

Solar collector area = 20.11 m²

Over shading = none

	Mode 2 Cold and bright	Mode 3 Cold and dull during the day	Mode 4 Night time
	Low temperature thermal store temperature °C (same as outside)	Low temperature thermal store temperature °C (same as outside)	Low temperature thermal store temperature °C (-5K below outside)
January	5.1	5.4	-1.1
February	6.1	6.7	-0.1
March	7.3	2.5	1.0
April	8.9	8.4	2.7
May	10.1	11.9	4.8
June	12.3	15.1	7.5
July	13.0	17.8	10.6
August	13.2	15.5	9.2
September	12.2	14.9	7.2
October	10.8	11.3	4.7
November	7.7	8.2	1.8
December	6.7	7.6	1.2

Table A3 – Low temperature thermal store temperature for Mode 2, 3 and 4.