Waste Water Heat Recovery Systems (Instantaneous Shower): Method statement for recognition in SAP

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Table of Symbols

Symbol	Description
A	First hot water usage coefficient (eg A = 25 in 25 x N_{occ} + 38 litres/day, SAP 2005)
$A_{w,m}$	First monthly hot water savings coefficient
B	Second coefficient hot water usage coefficient (eg B = 38 in 25 x N_{occ} + 38 litres/day, SAP 2005)
$B_{w,m}$	Second monthly hot water savings coefficient
C_{hx}	Specific heat capacity of dry heat exchanger
C_p	Specific heat capacity of water
F_{ba}	Fraction of hot water used in the dwelling for bathing (i.e. that used in a shower or bath)
F_{hw}	Fraction of hot water in a mixer shower
l	Length of preheated water pipe installed after the heat exchanger
M_{hx}	Is the mass of the heat exchanger (dry)
$N_{bth+shr}$	Number of baths and showers with or without systems fitted.
$N_{sh\&bth,n}$	Number of mixer showers fitted with WWHRS “n” in rooms with a bath
$N_{shxbth,n}$	Number of mixer showers fitted with WWHRS “n” in rooms without a bath
N_{occ}	Number of occupants
N_{sd}	the average number of showers per occupant per day
Q_{rec}	Energy recovered
r	Internal radius of the connecting preheated water pipe
SB_{mix}	the average amount of water used in showers divided by the total used in both baths and showers
T_c	Cold water mains temperature
T_{drain}	Temperature of water exiting the shower
T_{mix}	Temperature of shower at the head
$T_{drain,out}$	Temperature of the waste water exiting the heat exchanger
UA_{hx}	The specific rate of heat transfer (W/K) or “UA” of the heat exchanger
UF	Utilisation factor
V	the volume flow through the heat exchanger
V_{hx}	The volume of water in the heat exchanger.
V_{mix}	the daily volume used by showers
v_{mix}	the average volume of a shower
$W_{f,m}$	Monthly hot water factor (SAP 2009, table 1c)
ΔT	Water heating temperature rise i.e. $\left(T_c - T_h\right)$
ρ	Density of water
η	Heat exchanger efficiency as known as effectiveness
$\bar{\eta}$	The weighted mean efficiency of a number WWHRS and configurations

1 Introduction

In 2008, Chris Martin of the Energy Monitoring Company Ltd, under contract to Solar Imagination Limited, submitted a document proposing a method for recognition of waste water heat recovery systems in SAP Appendix Q (ref 1). The proposal was scrutinised by BRE and recognition of a method was implemented in Appendix Q of SAP 2005. In 2010, the method was adapted for inclusion in Appendix G of SAP 2009.

Since the publication SAP 2009, appendix G, the value of parameters, such as shower temperatures and flow rates, were reviewed (ref 2) resulting in proposed changes for inclusion in the draft version of SAP 2012, appendix G (ref 3).

This document describes the technical basis of the method for recognition of such systems in SAP and the data requirements. It draws heavily on the work of Chris Martin's original proposal, which is also outlined within this document.

Waste water heat recovery systems (WWHRS), specifically Instantaneous Shower Heat Recovery, recover some of the heat in the waste water from showers. They rely on the waste water flowing thorough a counter flow heat exchanger that pre-warms the cold water feed to a shower mixer and a combi-boiler or an unvented hot water cylinder. For heat to be recovered there must be a simultaneous flow of waste water and cold water through the heat exchanger hence they can only recover waste water from a shower and not, for example, a bath.

Part 2 defines the efficiency, also known as the effectiveness, of a counter flow heat exchanger.

Part 3 derives the theory adopted to estimate the potential savings based on number of parameters. Part 4 derives the parameter values.

Parts 5, 6.1 and 6.2 apply the method to SAP 2005 Appendix Q, SAP 2009 and SAP 2012, appendix G (consultation version).

Part 7 describes the necessary data requirements to achieve recognition of Instantaneous Shower Heat Recovery WWHRS products in SAP.

WWHRS reduces the hot water demand and hence decreases the solar utilisation factor in Appendix H of SAP. For more details see G2.3 of SAP 2009 (ref 4) or 2012 (ref 3)

2 Counter flow heat exchanger efficiency

The efficiency of a counter flow heat exchanger is:

$$\eta = (T_{drain} - T_{drain,out}) / (T_{drain} - T_c) \qquad 1$$

where 'T_{drain}' and '$T_{drain,out}$' is the inlet and outlet temperature of the warm stream (waste water stream) and 'T_c' is the inlet temperature of the cold stream (cold water mains supply) (see 18.39 ref 10).

The energy recovered is:

$$Q_{rec} = V \rho C_p (T_{drain} - T_{drain,out}) \qquad 2$$

where 'V' is the volume of water flow through the heat exchanger on the hot side; 'ρ' is the density of water, and 'C_P' the heat capacity of water. This ignores any changes in water density and specific heat capacity with temperature, since temperature range is relatively small.

Rearranging (1) to give $(T_{drain} - T_{drain,out}) = \eta(T_{drain} - T_{cold})$ and substituting this into (2) to eliminate $(T_{drain} - T_{drain,out})$ gives the energy recovered per shower

$$Q_{rec} = V \rho C_p \eta (T_{drain} - T_c) \qquad 3$$

where 'T_c' is cold water mains temperature entering the heat exchanger.

3 Approach

Two approaches were considered to work out the shower water volume in a dwelling and hence the energy saved: a bottom-up and a top-down approach.

3.1 The bottom-up approach

This approach starts by considering the water consumption of an individual shower and scales it up from the knowledge of the average number of showers per occupant per day.

So for a given number of occupants, N_{occ}, the daily shower volume is:

$$V_{mix} = v_{mix} N_{occ} N_{sd} \qquad 4$$

N_{sd} is the average number of showers per occupant per day
v_{mix} is the average water volume flowing through a shower
V_{mix} is the average daily volume of water used by showers

Most installations will contain a mixture of baths and showers, some with or without WWHRS fitted, therefore the savings will vary according to number of baths and showers and WWHRS installed. To account for this an average efficiency ($\bar{\eta}$) is worked out for the number of showers with a system fitted and the number of baths and showers without a system fitted.

If baths are installed the occupants have the option of taking a bath rather than a shower. As there is not a simultaneous flow of cold water and waste water through the heat exchanger when draining a bath, no energy can be recovered. To account for this the efficiency of WWHRS installed in a shower over a bath is reduced by a fraction (SB_{mix}) – the amount of water used for showering in the general population divided by the total amount used in the general population used for showering and bathing.

From (3) and (4) the daily energy saved expressed in terms of the average efficiency for a number of possible installations is:

$$Q_{sav} = v_{mix} C_P \bar{\eta} (T_{drain} - T_{main}) N_{occ} N_{sd} \qquad 5$$

where '$\bar{\eta}$' is the average efficiency of showers in the dwelling, taking into account the number of showers, baths and showers over baths, as defined in (6) using the parameters defined in table 1.

Table 1: Number of baths and showers parameters

Description of parameter	Symbol
Number of showers, mixer or Instantaneous Electric Shower (IES), with or without systems fitted plus number of baths in rooms without showers.	$N_{bth+shr}$

Number of mixer showers fitted with WWHRS 1 in rooms with a bath	$N_{sh\&bth,1}$
Number of mixer showers fitted with WWHRS 1 in rooms without a bath	$N_{shxbth,1}$
Number of mixer showers fitted with WWHRS 1 in rooms with a bath	$N_{sh\&bth,2}$
Number of mixer showers fitted with WWHRS 1 in rooms without a bath	$N_{shxbth,2}$
and so on…..	
Number of mixer showers fitted with WWHRS n in rooms with a bath	$N_{sh\&bth,n}$
Number of mixer showers fitted with WWHRS n in rooms without a bath	$N_{shxbth,n}$

$$\bar{\eta} = [\Sigma\left(N_{sh\&bth,i} \times SB_{mix} \times \eta_i \times \ UF_i\right)_{i=1,2..n} + \Sigma\left(N_{shxbth,i} \times \eta_i \times UF_i \ \right)_{1,2..n}] \div \left(N_{bth+sh}\right) \qquad 6$$

Where 'SB_{mix}' is the average amount of water used in showers divided by the total used in both baths and showers.

'UF ' is a utilisation factor and accounts for the time the WWHRS takes to reach steady-state (see part 6.1).

A shower is defined when it supplies a shower head fitted to a fixture and can include showers over a bath or dedicated showers. Shower heads not fixed to the wall or ceiling above head height are ignored.

The potential energy recovered by an instantaneous electric shower (IES) is not recognised because the device is likely to receive an improvement in service delivery via an increased flow rate and therefore not reduce the energy consumption of the shower.

3.2 The top-down approach

This approach starts from whole house hot water consumption and apportions the amount used by showers to calculate energy savings.

The daily energy content of hot water supplied is:

$$(AN_{occ} + B)C_p\rho \qquad 7$$

Where 'A' and 'B' are coefficients that relate daily hot water usage to number of occupants (e.g. 25 x N_{occ} + 38 litres/day in SAP 2005)
'ρ' is the density of water
'C_p' is the specific heat capacity of water.

The fraction of hot water used in the dwelling for bathing (i.e. that used in a shower or bath) is 'F_{ba}' and the fraction of hot water in a shower is 'F_{hw}'. Therefore, the total daily energy content of the water (hot and cold) of a shower is:

$$Q_{sh} = (AN_{occ} + B)C_p \rho F_{ba} / F_{hw} \tag{8}$$

The energy saved is (8) x fraction of energy recovered $\bar{\eta}(T_{drain} - T_c)$ which is:

$$Q_{sav} = (AN_{occ} + B)C_p \rho \bar{\eta}(T_{drain} - T_c)F_{ba} / F_{hw} \tag{9}$$

Note '$\bar{\eta}$' is the average efficiency of all the showers and baths in the property (see (6) in part 2.2)

3.3 Combining the methods

It was decided that the best approach was to use the numerical average of the bottom-up and top-down approach.

So averaging (9) and (5) gives:

$$2Q_{sav} = (AN_{occ} + B)C_p \rho \bar{\eta}(T_{drain} - T_c)F_{ba} / F_{hw} + v_{mix} C_P \bar{\eta}(T_{drain} - T_{main})N_{occ} N_{sd} \tag{10}$$

Rearranging gives;

$$\boxed{Q_{sav} = \frac{\rho}{2} C_P \bar{\eta}(T_{drain} - T_c)(AN_{occ}\frac{F_{ba}}{F_{hw}} + B\frac{F_{ba}}{F_{hw}} + v_{mix} N_{occ} N_{sd})} \tag{11}$$

Equation (11) shows the potential daily savings (in kJ/day) expressed in terms of a number of parameters. Section 4 proceeds to establish their values.

3.4 Low water usage dwelling

Dwellings designed to use less than 125 litres/person/day of water (total hot and cold water) are credited in monthly versions of SAP by reducing the hot water usage by 5%. This is achieved in SAP by reducing the coefficients 'A' and 'B' by 5%, which will also reduce energy savings (see equation 11). However, v_{mix}, which is the average water volume flowing through a shower, does not reduce by 5%, since dwellings compliant with Approved Document Part G of the Building Regulations typically utilise alternative measures to reach the 125 litres/person/day target, i.e. do not utilise shower flow restrictors.

The effect on WWHRS calculations for low water usage dwellings is included from SAP 2012 onwards.

4 Parameter values

4.1 Cold water supply temperature

In SAP 2005 (ref 5) the cold water supply temperature (T_c) is not stated. It simply requires a temperature rise of 50ºC. Therefore taking the hot supply as 60ºC leaves the cold supply at 10ºC. In SAP 2009 it varies monthly (table G2, ref 4) which is based on data from an Energy Saving Trust (EST) study (ref 6).

4.2 Shower drainage temperature

'T_{drain}' is temperature of the shower water as it enters the shower drain hole. Typical shower head water temperatures of 41ºC measured in the laboratory by Liverpool John Moores University (ref 7, figure 17 for mixer showers) indicate water temperature falls by 5.9ºC in the shower, giving a drain temperature of 35.1ºC, say 35ºC for simplicity.

4.3 A and B parameters.

In SAP 2005 (25 N_{occc} + 38) and SAP 2009 (25 N_{occ} + 36)

4.4 Number of showers per day

'N_{sd}' is the average number of showers per occupant per day. Table 8, ref 7, states for 223 homes without water meters (i.e. older properties) that the average number is 0.7 showers per person per day.

4.5 Fraction of hot water used for bathing.

'F_{ba}' is the fraction of the total dwelling hot water usage that is used for bathing (i.e. used in showers or baths).

The following table shows an estimated value of 'F_{ba}'. Column A is based on a reliable estimate. Column B is estimated and assumes most washing machines are cold filled only, with 62% of hot water derived from equation (12) for SAP 2005. For SAP 2009, this value varies monthly but does not vary the value of 'F_{ba}' significantly. The inside tap use is assumed to be predominantly cold water, hence allocating 30% due to kettle and saucepan filling etc. The leakage is assumed to be all cold water because any hot water leakage is assumed to be rectified quickly. The unknown usage is a proportion that cannot be assigned with any degree of certainty to the tabled uses, but a proportion of 25% to hot water supply is assumed.

Table 2: Water use by end of use

Type of use	Cold and hot water usage by type Col A (ref 8)	Estimated % of hot water Col B	Col A x Col B	Hot water usage by type
Bath	16.20%	62.0%	10.0%	44.3%
Shower	7.90%	62.0%	4.9%	21.6%
Subtotal for bathing and showering F_{ba} =				66.0%
Washing machine	13.60%	0.0%	0.0%	0.0%
Dish washing	1.50%	0.0%	0.0%	0.0%
Unknown	2.20%	25.0%	0.6%	2.5%
leakage	1.60%	0.0%	0.0%	0.0%
Inside tap	23.10%	30.0%	7.2%	31.4%
Outside tap	4.10%	0.0%	0.0%	0.0%
Toilet	29.90%	0.0%	0.0%	0.0%
	100.10%		22.42%	

4.6 The volume of hot water in an average shower.

'v_{mix}' is the volume of water in an average shower.
It is difficult to estimate this quantity because flow rates and shower duration vary considerably.

NHBC minimum and maximum design flow rates are 6 and 12 litres/min (table 4, ref 11).

The next table shows estimated shower volumes as reported by the Liverpool John Moores University research paper by shower type. This average was adopted for the SAP 2005 appendix Q calculation (i.e 75 litres).

Table 3: Typical shower flow rates and volumes (table 8, ref 7).

Shower type	Flow rate	Duration	Volume
Mixer shower (short duration)	8 l/min	5.8 min	46.4 litres
Mixer shower (long duration)	8 l/min	9 min	72 litres
Pumped showers	12 l/min	9 min	108 litres
Average			75.4 litres

The mixer showers defined in the table above are gravity-fed and mains pressure systems. The short duration is based on average use in 233 homes without water meters (i.e. older homes) monitored by the WRc and the long duration is based on 31 volunteers in 16 homes monitored by LJMU study.

The flow rate of 8 l/minute was reduced by LJMU from the 11.5 litres/min monitored in the small study because the small study contained mixer showers at the higher end of flow rate range of 5-15 litres/min..

Table 4 gives the average flow rate that separates gravity fed and pressurised systems used by Market Transformation Programme for demand forecasting model for shower water consumption reported in the Policy Brief for showers.

Table 4: Typical shower flow rates (table 1, ref 9).

Mixer shower type	Flow rate
Gravity fed	7.9 l/min
Integrated pumped shower	9.85 l/min
Separate pump or mains pressure feed	11.8 l/min
Bath/shower	6 l/min

Table notes:

1) It is unclear what is meant by bath/shower but presumably this is a shower fed from the hot and cold bath taps; which could be mains pressure or gravity fed.

2 These are not measured rates but typical rates used in the MTP water demand modelling program.

A paper by Durham University reports on two substantial studies of measured shower flow rates (ref 12). Its appendix shows that 346 Warmfront homes before any improvements were added[1] surveyed by EAGA with combi boilers reports that mean population flow is expected to lie between 8.9 ± 0.37 litres/min for 346 pre-warm front homes with 95% confidence. For mains pressure tank systems the mean flow rate is expected to lie between 8.8 ± 0.30 litres/min for 449 homes.

The second study within the Durham University report was for 204 homes fitted with newer heating systems. Mains pressure showers resulted in a skewed distribution with a mean flow rate of 11.28 litres/min (see figure 5, ref 12). The mode (i.e. the most common value) is 9 litres/min.

Average shower times and frequency were also recorded for the 204 homes study by occupants over weekly periods. The shower frequency was 5.01 showers per person per week with 95% confidence for the population mean of 5.01[2] ± 0.23 showers per person per week. Average recorded shower times were 6.47 with the population expected to lie between 6.47 ± 0.4 minutes.

Note a WRc study of 233 homes (ref 8) without water meters (i.e. older properties) noted an average of 28.4 litres per shower for 5.8 minutes at 5.3 litres/min from directly feed showers (i.e. from combi boilers or electric instantaneous showers) which is considerably less than the above (Table 8, ref 7) but will not be typical of new homes. The Market Transformation Briefing (ref 9) also cites 41 litres per shower, but this is an average across all shower types, and again includes instantaneous electric showers (IES) which typically have lower flow rates.

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[1] Warmfront is a government funded scheme that offers free energy efficiency improvements including insulation and new heating systems to eligible households (older person and poor households).

[2] Note 5.01 showers per person per week is 0.71 showers per person per day and is very close to the value of 0.7 in part 3.4

A key assumption is that Instantaneous Shower WWHRS only work with pressurised systems to ensure identical flow rates through the drainage side and cold water side of the heat exchanger. Bearing this in mind the only relevant shower type flow rate data to consider is the mains pressure mixer type. Durham University reported (ref 12) on measurements in 449 and 204 homes and is by far the most robust for this purpose, reporting a mean flow rates of 8.88 litres/min and 11.28 litres/min respectively. The larger sample corresponds to homes surveyed as part of the application for the Government grants for replacement boilers or insulation measures. The smaller sample included some of the same homes after the new combi boilers were installed and some from the social housing sector. The samples are therefore biased away from larger wealthier households.

The smaller sample also noted shower time recorded by occupants and has a mean value of 6.5 minutes. Ref 8 recorded 5.8 minutes and is based on a sample of 46 homes and included some electric showers.

It was necessary to define the flow rate used for WWHRS efficiency measurements in a test laboratory, since this was not explicitly defined within SAP 2005, where product applicants used a standard test flow rate of 7.5 litres/min (NEN5128 A1:2009). For SAP 2009, the flow rate used for efficiency measurements was amended to 9 litres/min. The efficiency value is then utilised in Equation (6).

A duration of 6.5 minutes and a flow rate of 9 litres seems a reasonable assumption when considering that flow rates exclude the effect of any flow restrictors. The assumptions equate to a total shower volume of 58.5 litres. The above considerations were carried out after the assumed shower volume was fixed in SAP 2005 and SAP 2009 models, so the original assumption of 75 litres per shower will remain valid for the lifetime of SAP 2005 and SAP 2009 and is used for derivation of the ‘top-down approach’.

4.7 Fraction of hot water in a shower

‘F_{hw}’ is the fraction of hot water in a shower and can be determined by considering the conservation of the mass and energy of the water entering and leaving the shower head.

$$F_{hw} = \frac{T_{mix} - T_c}{T_h - T_c} \qquad 12$$

‘T_h’ and ‘T_c’ is the temperature of the hot water and cold water before mixing and ‘T_{mix}’ is the temperature of the mixed water.

For SAP 2005: ‘T_h’= 60ºC, ‘T_c’=10ºC, and ‘T_{mix}’= 41 ºC which gives ‘F_{hw}’= 0.62.

For SAP 2009 there is a monthly variation in 'T_c' based on the EST paper (ref 6). The yearly average temperature rise is 37ºC, but this also varies monthly (see table 1d) which means that 'F_{hw}' will also vary monthly.

4.8 Proportion of water used in shower

This is the average amount of water used in a shower, divided by average amount used in a shower and a bath (SB_{mix}). This figure was derived in the original WWHRS application which states:

"The Market Transformation Programme document which summaries water consumption in new and existing dwellings [6][3] indicates that baths are used on average 1.17 times a day and that showers are used 1.86 times. The average water used in a bath is 68.55 litres. Shower consumption is given as 41.17 litres, but this is an average across all types of shower. Using distinct figures derived for mixer and electric showers gives the value for SB_{mix} as shown in the table below."

Table 5 : Calculation of shower bath water mix

	Frequency of use per day	Consumption per event	Daily consumption	SB_{mix}
Bath	1.17	68.55	80.2	
Shower	1.86	75	139.5	0.635

(i.e. 0.635 = 139.5 /(80.2 + 139.5)

5 SAP 2005 Application

The savings are quantified according to equation (11) in part 2 is

$$Q_{sav} = \frac{\rho}{2} C_P \bar{\eta} (T_{drain} - T_c)(AN_{occ} \frac{F_{ba}}{F_{hw}} + B \frac{F_{ba}}{F_{hw}} + v_{mix} N_{occ} N_{sd})$$

Inserting the tabulated values into (11) for SAP 2005 gives:

$$Q_{sav} = 4.19\bar{\eta}(T_{drain} - T_c)(39.6N_{occ} + 20.2) \text{ kJ/day} \qquad 13$$

$$Q_{sav} = 4.19\bar{\eta}(T_{drain} - T_c)(39.6N_{occ} + 20.2) \text{ x } 365/3600 \text{ kWh per year} \qquad 14$$

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[3] [6] is part of a quotation and therefore retained. It refers to "BNWAT28: Water consumption in new and existing homes version 1.0, March 2008, www.mtprog.com" which is reference 9.

Table 6:SAP 2005 values

Symbol	Value	Reference
C_P x ρ	4.19 kJ/litre/K	SAP 2005
T_{drain}	35ºC	3.2
T_c	10ºC	3.1
B	38 litres/day	3.3
A	25 litres/day/person	3.3
F_{ba}	0.66	3.5
F_{hw}	0.62	3.7
v_{mix}	75 litres	3.6
N_{sd}	0.7	3.4

6 SAP 2009 Application

Applying the appropriate parameter values in (11) and (12) a formula can be derived to estimate the monthly savings attributable to a WWHRS (15).

Equation (11) in part 2 is

$$Q_{sav} = \frac{\rho}{2} C_P \bar{\eta} (T_{drain} - T_c)(AN_{occ} \frac{F_{ba}}{F_{hw}} + B \frac{F_{ba}}{F_{hw}} + v_{mix} N_{occ} N_{sd})$$

If the cold water supply temperature and the hot water temperature at the shower head vary monthly and so will the fraction of hot water in a shower, F_{hw}.

Using (12) to eliminate 'F_{hw}' (11) becomes:

$$Q_{sav} = \frac{\rho}{2} C_P \bar{\eta} (T_{drain} - T_c)(AN_{occ} \frac{(T_h - T_c)F_{ba}}{(T_{mix} - T_c)} + B \frac{(T_h - T_c)F_{ba}}{(T_{mix} - T_c)} + v_{mix} N_{occ} N_{sd}) \qquad 15$$

Defining the parameters in (16), (17) and (18) then the daily savings and monthly savings can be expressed as (19) and (20) respectively.

$$\Delta T = (T_h - T_c) \qquad 16$$

$$A_{w,m} = [0.5 \times F_{ba} \times A \times (\Delta T_m)/(T_{mix} - T_{c,m})] + 0.5 v_{mix} N_{sd} \qquad 17$$

$$B_{w,m} = [0.5 \times F_{ba} \times B \times \Delta T_m / (T_{mix} - T_{c,m})] \qquad 18$$

$W_{f,m}$ a hot water usage factor to represent the monthly c in hot water demand

$$Q_{sav,m} = 4.19 \bar{\eta} (T_{drain} - T_c)[A_{w,m} N_{occ} + B_{w,m}] W_{f,m} \text{ kJ/day} \qquad 19$$

$$Q_{sav,m} = 4.19\overline{\eta}(T_{drain} - T_c)[A_{w,m}N_{occ} + B_{w,m}]W_{f,m}N_{d,m} / 3600 \text{ kWh/month} \qquad 20$$

where '$N_{d,m}$' is the number of days in the month.

Table 7: SAP 2009 parameter values

Symbol	Value	Reference
$\rho\ C_P$	4.19 kJ/litre/K	SAP 2009
T_{drain}	35^{o}C	4.2
T_c	Monthly value	Table 8
B	36 litres/day	4.3
A	25 litres/day/person	4.3
F_{ba}	0.66	4.5
v_{mix}	75 litres	4.6
N_{sd}	0.70	4.4
T_{mix}	41^{o}C	4.2

Table 8: SAP 2009 Monthly values derived from the EST field study (ref 6).

Symbol†	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
T_c ^{o}C (G2)	11.1	10.8	11.8	14.7	16.1	18.2	21.3	19.2	18.8	16.3	13.3	11.8
ΔT K (1d)	41.2	41.4	40.1	37.6	36.4	33.9	30.4	33.4	33.5	36.3	39.4	39.9
$W_{f,m}$ (1c)	1.1	1.06	1.02	0.98	0.94	0.9	0.9	0.94	0.98	1.02	1.06	1.1

† SAP table reference in brackets.

Inserting the tabulated values into (17), (18) and (20) gives

$$A_{w,m} = [0.33 \times 25 \times (\Delta T_m) / (41 - T_{c,m})] + 26.1$$

$$B_{w,m} = [0.33 \times 36 \times (\Delta T_m) / (41 - T_{c,m})]$$

$$Q_{sav,m} = 4.19\overline{\eta}(35 - T_{c,m})[A_{w,m}N_{occ} + B_{w,m}]W_{f,m}N_{d,m} / 3600 \text{ kWh/month}$$

SAP 2012 (consultation version)

The following parameter values were defined in *'Green Deal Occupancy Assessment Methodology', DECC*, (to be published in summer 2012). For future consistency it was decided to adopt them in the consultation version of SAP 2012 (ref 3).

1. Shower water flow rate 11 litres/min
2. Shower duration 6 minutes
3. Shower water volume 66 litres based on parameter 1 and 2.
4. Shower or bath water temperature reduced from 41°C to 40°C, therefore a drain temperature (WWHRS inlet) of 34°C.
5. Number of showers changed from 0.7 to 0.73 persons per day.
6. Number of baths changed to 0.21 per person per day.
7. Average water volume of bath is 50.8 litres.
8. The proportion of hot water used for bathing or showering reduced slightly from 0.66 to 0.61 based parameters 6 and 7.

The effect of the change in parameters 3, 4 and 8 is to reduce savings slightly.

Table 9: SAP 2012 parameter values

Symbol	Value	Reference
$\rho \ C_P$	4.19 kJ/litre/K	SAP 2009/2012
T_{drain}	34ºC	6ºC below T_{mix} (see 4.2)
T_c	Monthly value	See below
B	36 litres/day	SAP 2009/2012
A	25 litres/day/person	SAP 2009/2012
F_{ba}	0.610	Reference 2
v_{mix}	66 litres	Reference 2
N_{sd}	0.73	Reference 2
T_{mix}	40ºC	Reference 2

$$A_{w,m} = [0.30 \times 25 \times (\Delta T_m)/(40 - T_{c,m})] + 24.1$$

$$B_{w,m} = [0.30 \times 36 \times (\Delta T_m)/(40 - T_{c,m})]$$

$$Q_{sav,m} = 4.19\overline{\eta}(34 - T_{c,m})[A_{w,m}N_{occ} + B_{w,m}]W_{f,m}N_{d,m} / 3600 \quad \text{kWh/month}$$

Note 0.61 divided by 2 was rounded to 0.30.

In part 3.4, it was noted that dwellings designed to achieve less than 125 litres/person/day of water (total hot and cold) are given credit in the monthly versions of SAP by reducing the hot water usage by 5%. The effect is to reduce energy savings by reducing the values of 25 and 36 in the above equation by 5% when a 125 litres/person/day water consumption target is achieved.

To allow for future innovations of extracting heat from the waste bath water the shower-bath water mix, SB_{mix}, is no longer fixed but a value linked to each WWHRS model that is passed to SAP programs via the WWHRS data table.

$$\overline{\eta} = [\sum\left(N_{sh\&bth,i} \times SB_{mix} \times \eta_i \times \ UF_i\right)_{i=1,2..n} + \sum\left(N_{shxbth,i} \times \eta_i \times UF_i \ \right)_{1,2..n}] \div \left(N_{bth+sh}\right)$$

For units that extract heat only from the waste shower water the value is calculated as shown in table 10. For units that can extract waste heat from the bath water also it can be as high as unity.

Table 10 : Calculation of shower bath water mix

	Frequency of use per person per day	Consumption per event	Daily consumption per person	SB_{mix}
Bath	0.21	70	14.7	
Shower	0.73	66	48.2	0.766

i.e. 0.766 = 48.2 /(48.2 +14.7)

7 Data requirements

7.1 Efficiency measurement

A key requirement for recognition of Instantaneous Shower WWHRS in SAP is that a measured efficiency from an independent test laboratory must be provided.

The efficiency will vary with flow rate. In part 3.6 the average flow rate volume was deduced as 9 litres/min for mains pressure mixer showers. Therefore, to be recognised in SAP 2009 the measured efficiency of Instantaneous Shower WWHRS was taken to be 9 litres/min. Interpolated values may be used if measurements span this value.

For the SAP 2012 the required flow rate for recognition is 11 litres/min.

7.2 Utilisation factor

This factor was introduced to account energy losses not included in the laboratory data but likely to occur in an installation. These are the energy required to warm-up the heat exchanger, any energy left over in the pipe work at the end of the shower and heat losses from the connecting pipework whilst the shower is in operation.

The energy required to warm-up the heat exchanger is lost at the end of the shower. The measured efficiency will partly include this loss but as the measurement duration (e.g. 14 minutes) is much longer than the average shower duration (6 minutes), this loss will be a bigger proportion of the total energy content of the shower.

The heat loss from the pipework between the shower drain and the device for the duration of a shower can be calculated from:

$$\dot{Q} = \frac{2\pi(T_1 - T_\infty)k}{\dfrac{k}{hr_2} + \ln(r_2/r_1)}.$$

(source reference 10, 17.26)

$\dot{Q}$	is the heat loss rate from a cylinder of inner radius r_1 and outer radius r_2 per unit length per unit temperature difference.
T_1	is the temperature of fluid inside
T_∞	Is the temperature outside the pipe
k	is the conductivity of the pipe
h	is the surface heat transfer coefficient

The heat loss for a typical installation from a plastic drainage pipe connecting the shower outlet to the device with an outside diameter of 40mm[4] and thickness 1.8mm, k= 0.15 W/m/K, drainage temperature of 34ºC and room temperature of 20ºC, and h = 7.7 W/m^2/K (horizontal heat transfer in still air) is 12.4 W per meter run.

Taking 3m as the typical pipe run between the shower drain and the device, the heat loss during a shower is 37 Watts. This loss will only occur during a shower (6 minutes) and equates to 0.0037 kWh or 0.25% of the energy available to extract in shower of 66 litres. The equation is based on a horizontal pipe filled with fluid up to the top. In practice drainage pipes are not completely filled and therefore the heat loss with even less.

This amount is insignificant and so can be safely neglected.

There will also be heat loss during a shower from copper pipework connecting the mixer tap or boiler or cylinder to the device. A 15mm copper pipe of 3m has a heat loss (3 x 13W/m[5]), over six minutes this equates to 0.28% of heat that can be extracted be from the shower waste. Hence it also can be safely neglected.

The main energy loss related to the connecting copper and plastic pipework occurs at the end when the leg of water in the drainage inlet and pre-warmed outlet eventually cools. This energy loss is taken into account in the utilisation factor.

Defining the utilisation factor as:

UF = 1- total energy lost ÷ energy transferred per shower 22

The amount of water wasted

Assuming all the heat content of the wet heat exchanger and the water in the surrounding pipe work (pre-heated outlet and drainage inlet) and is lost at the end of the shower then appendix A (A10) shows that:

$$UF = 1 - \frac{2000 l \pi r^2 \rho C_p \eta + 0.5(\rho C_p V_{hx} + M_{hx} C_{hx})}{V \rho C_p \eta} \qquad 23$$

- C_{hx} is the specific heat capacity of the heat exchanger (kJ/kg/K)
- l is the length of the connecting pipe work (m) taken as 3m of inner radius *r*. If the water drains directly into the device this is halved so only pre-warmed water of device outlet pipes is counted as lost.
- V is the volume of water per shower (58.5 litres or 66 litres)
- ρ is the density of water (1 litre/kg)

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[4] http://www.pipestock.com/pvc-pipe-dimensions/

[5] http://www.engineeringtoolbox.com/copper-pipes-heat-loss-d_51.html 21W for 22K temperature difference equates to 13.4W for 14K temperature difference.

- C_p is the specific heat capacity of water (4.2 kJ/kg/K)
- M_{hx} is the mass of the heat exchanger in kg
- V_{hx} is the volume of water in the heat exchanger in litres
- η is the efficiency as known as the effectiveness
- r is the inside radius of the connecting preheated water outlet pipe work (m)
- x2000 – x1000 converts to litres and x2 assumes the wasted drainage water is the same volume as the wasted preheated water.

Some heat exchangers are fitted directly into shower trays. In the case we only need to count the wasted water in pre-warmed outlet pipe and so removed the x2 multiplication. This identical to halving the pipe length from 3m to 1.5m instead and is a more convenient way of calculating it.

The Instantaneous Shower WWHRS manufacturer/supplier needs to provide in order to calculate the utilisation factor, the dry heat exchanger thermal mass, volume of water in the heat exchanger, the inside radius of the water outlet pipe from the device, and whether the device is part of the shower tray.

8 Imbalanced configurations

A key assumption of the method is that there are identical flow rates through the warm and cold side of the heat exchanger (i.e. the system is balanced). This can only be achieved if the device supplies both the mixer shower and the cold feed of a hot water source (i.e combi boiler or unvented hot water tank).

If this assumption is invalid then the efficiency can be downgraded according to the process noted in appendix B.

9 References

1. C Martin, Assessing the energy saving potential of the Showersave and the development of SAP Appendix Q method, version 2.0, November 2008, Energy Monitoring Company Ltd.

2. *Green Deal Occupancy Assessment Methodology*, DECC, (to be published summer 2012)

3. The Government's Standard Assessment Procedure for Energy Rating of Dwellings 2012 Draft Edition, produced for DECC by BRE, www.bre.co.uk/filelibrary/SAP/2012/Draft_SAP_2012_December_2011

4. The Government's Standard Assessment Procedure for Energy Rating of Dwellings 2009 edition with corrections, May 2010, produced for DECC by BRE, www.bre.co.uk/SAP2009.

5. The Government's Standard Assessment Procedure for Energy Rating of Dwellings, 2005 Edition produced for DEFRA by BRE www.bre.co.uk/SAP2005.

6. Measurement of Domestic Hot Water Consumptions in Dwellings. EST report to DEFRA 2008.

7. Richard Critchley and Dr David Phipps, Water and Energy Efficient,Showers: Project Report, United Utilities and Liverpool John Moore University, May 2007.

8. Dene Marshallsay, Understanding domestic water use in the context of demand management and forecasting, WRc plc www.idswater.com/common/paper/paper_13/understanding%20domestic%20water%20use%20in%20the%20context.htm, last accessed 12/07/2011.

9. BNWAT28: Water consumption in new and existing homes version 1.0, March 2008, www.mtprog.com, last accessed 12/07/2011.

10. Prof. Z. S. Spakovszky 16.Unified: Thermodynamics and Propulsion Lectures, section 18.5, MIT, http://web.mit.edu/16.unified/www/FALL/thermodynamics/notes/node131.html, last accessed 24/10/2012.

11. Water efficiency in new home, an introductory guide for housebuilders, published by IHS BRE Press on behalf of the NHBC Foundation, revised July 2010.

12. Dr D.B. Sims-Williams, Dr H.A. Bulkeley, Dr P.C. Matthews, Mr G.D. Powells, Potential water savings through the use of HL2024 shower flow regulators. Durham University, May 2008.

Appendix A - Definition of the utilisation factor.

Defining the utilisation factor as:

UF = 1- (total energy lost ÷ energy transferred per shower) A1

Assuming all the energy required to warm-up the thermal mass of heat exchanger and the water in the associated pipe work is lost at the end of a shower the utilisation factor is:

$$UF = 1 - \frac{Q_{hx} + Q_{pp}}{Q_{rec}} \qquad \text{A2}$$

where

Q_{hx} is the energy lost from the water in the heat exchanger

Q_{pp} is the energy lost from the water in the connecting pipes.

Q_{rec} is the energy recovered from a shower.

Each term of the three terms are now defined

Assuming the energy content of the water in the pipes on the drainage side of the heat exchanger is the same as that in the pipes on the heated side, the energy content of the connecting pipework is:

$$Q_{pp} = l\pi r^2 \rho C_p (T_{c,out} - T_c) + l\pi r^2 \rho C_p (T_{drain} - T_{drain,out}) \qquad \text{A3}$$

Where
l is the preheated pipe run length (m)
r is the inside diameter of preheated supply pipe (m)
π is the constant (the circumference divided the diameter of a circle)
1000 converts from m^3 to litres

For a balanced system $(T_{c,out} - T_c) = (T_{drain} - T_{drain,out})$ A3 simplifies to:

$$Q_{pp} = 2l\pi r^2 \rho C_p (T_{drain} - T_{drain,out}) \qquad \text{A4}$$

The energy content of heat exchanger (water and dry mass of heat exchanger) lost at the end of shower is:

$$Q_{hx} = (\rho C_p V_{hx} + M_{hx} C_{hx})\left(\frac{(T_{drain} + T_{drain,out} + T_{c,out} + T_c)}{4} - T_c\right) \qquad \text{A5}$$

Where V_{hx} is the volume of water in the heat exchanger of dry mass M_{hx} and specific heat capacity of C_{hx}.

The total energy transferred is:

$$Q_{rec} = V \rho C_p \eta (T_{drain} - T_c) \qquad \text{A6}$$

Substituting (A4), (A5) and (A6) into (A2) gives:

$$UF = 1 - \frac{2l\pi r^2 \rho C_p (T_{drain} - T_{drain,out}) + (\rho C_p V_{hx} + M_{hx} C_{hx})(\frac{(T_{drain} + T_{drain,out} + T_{c,out} + T_c)}{4} - T_c)}{V \rho C_p \eta (T_{drain} - T_c)} \tag{A7}$$

Using (1) $\eta(T_{drain} - T_c) = (T_{drain} - T_{drain,out})$ to eliminate $(T_{drain} - T_{drain,out})$ then A7 becomes:

$$UF = 1 - \frac{2l\pi r^2 \rho C_p \eta (T_{drain} - T_c) + 0.25(\rho C_p V_{hx} + M_{hx} C_{hx})(T_{drain} - T_c + T_{drain,out} - T_c + T_{c,out} - T_c)}{V \rho C_p \eta (T_{drain} - T_c)} \tag{A8}$$

Noting for a balance system $(T_{c,out} - T_c) = (T_{drain} - T_{drain,out})$ A9

$$UF = 1 - \frac{2l\pi r^2 \rho C_p \eta (T_{drain} - T_c) + 0.25(\rho C_p V_{hx} + M_{hx} C_{hx})(T_{drain} - T_c + T_{drain,out} - T_c + T_{drain} - T_{drain,out})}{V \rho C_p \eta (T_{drain} - T_c)}$$

$$UF = 1 - \frac{2l\pi r^2 \rho C_p \eta (T_{drain} - T_c) + (\rho C_p V_{hx} + M_{hx} C_{hx}) 0.25 \times 2 \times (T_{drain} - T_c)}{V \rho C_p \eta (T_{drain} - T_c)}$$

Finally dividing top and bottom by $(T_{drain} - T_c)$ and converting volumes in litres gives:

$$UF = 1 - \frac{2000 l\pi r^2 \rho C_p \eta + 0.5(\rho C_p V_{hx} + M_{hx} C_{hx})}{V \rho C_p \eta} \tag{A10}$$

- M_{hx} is the mass of the heat exchanger (kg)
- C_{hx} is the specific heat capacity of the heat exchanger (J/kgK)
- V_{hx} is the volume of water in the heat exchanger (Litres)
- η is the efficiency or effectiveness
- V is the volume of water per shower (Litres) (66 litres for SAP 2012 and 58.5[6] litres SAP 2009)
- ρ is the density of water (kg/litre)
- C_p is the specific heat capacity of water (J/kgK)
- l is the installed pipe run length (preheated water output from heat exchanger to shower). 3m is taken as typical. If the heat exchanger is wholly contained within the shower base unit the value is halved to remove the drainage side waste
- r is the inside radius of the preheated pipe work

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[6] The shower volume in SAP 2009 is 75 litres, but for utilisation factor calculation an intermediate value of 58.5 was erroneously used, representing an error of less than 1%. The shower volume of 58.5 litres is used for all SAP 2009 WWHRS products for consistency. This will be increased to 66 litres for SAP 2012 Utilisation Factor calculations.

Appendix B - Unbalanced systems

B1 Efficiency

A key assumption of the method is that there are identical flow rates through the warm and cold side of the heat exchanger simultaneously (i.e. the flow rates are balanced). This can be achieved only by the device supplying both the mixer shower and the cold feed of a combi boiler or hot water tank (unvented).

If this assumption is invalid then the efficiency is downgraded as follows.

1. Noting that the specific rate of heat transfer (W/K) of the heat exchanger, UA_{hx}, is related to the efficiency, η, by B1, solve for a value of UA_{hx} using the measured flow rates and efficiency of the certified test.

$$\eta = \frac{1-e^{-\alpha}}{1-\frac{m_{drain}}{m_{pre}}e^{-\alpha}} \qquad \text{B1}$$

where

$$\alpha = UA_{hx}\left(\frac{1}{m_{drain}} - \frac{1}{m_{pre}}\right)$$

m_{drain} is the heat flow rate on the drainage side of the heat exchanger

m_{pre} is the heat flow rate in the cold side of the heat exchanger

The heat flow rate (m_x) in W/K is related to volume flow rate by $m_x = 4200 f_x / 60$ where f_x is the volume flow rate in litres/min and 4.2 kJ/kgK is the specific heat capacity of water.

Important note: when $m_{drain} = m_{pre}$ a special solution is necessary: so first add and then subtract a small amount (0.5 W/K) to m_{drain} to obtain two values of η. Take the average of the two values to obtain the efficiency when $m_{drain} = m_{pre}$.

2. From the UA_{hx} value, calculate the efficiency of a balanced flow rate of 9 litres/min (630 W/K)

3. For an unbalanced system when the system preheated water outlet is only fitted to the shower supply, known as 'System B' configuration.

a. Calculate an initial efficiency from (B1) using the UA_{hx} and an initial value of m_{pre} = 300 W/K

b. Calculate a revised temperature (T_{pre})

$$T_{pre}\ (\text{next}) = T_c + \eta\ \left(T_{drain} - T_c\right)\ \frac{m_{drain}}{m_{pre}} \qquad \text{B2}$$

c. and hence a revised m_{pre}

$$m_{pre}(\text{next})\ =\ m_{drain}\ \ \frac{\left(T_{hot} - T_{mix}\right)}{\left(T_{hot} - T_{pre}(next)\right)} \qquad \text{B3}$$

d. Calculate a revised efficiency using (B1) using $m_{pre}(\text{next})$

e. Repeated steps b, c and d until $m_{pre}(\text{next})$ - $m_{pre}(\text{previous})$ is within the range ±0.001 W/K

f. Note the efficiency when solution has converged. This is the efficiency when the system is unbalanced with its preheated water outlet connected to the shower only.

4. Efficiency for an unbalance system when the system preheated water outlet is connected to the boiler or unvented hot water tank, known as ‘System C’ configuration. This does not need iteration.

   a. Calculate the rate of heat flow warmed by heat exchanger:

$$m_{pre} = m_{drain}\ \frac{(T_{mix} - T_c)}{(T_{hot} - T_c)} \qquad \text{B4}$$

   b. Calculate the efficiency from (B1) using the value of m_{pre} and the UA_{hx} of the heat exchanger.

In monthly versions of SAP T_{hot} and T_c will vary monthly. Therefore, 12 monthly efficiencies are first calculated. The monthly values are then averaged by evaluating (21) with12 monthly weighting factors of $\overline{\eta}$ =1.The utilisation factor in Appendix A (A10) is derived assuming balanced system conditions. For simplicity in SAP 2005/2009, (A10) is also applied to unbalanced systems as differences in savings are likely to small (i.e. of the order of 1 or 2%). However, this will change for SAP 2012 – see Appendix B2.

B2 Utilisation factor unbalanced systems

The utilisation factor derived in Appendix A (equation A10) is constrained to a balanced system. The appendix shows what happens if we relax the constraint.

From the definition of the utilisation factor (see A2) without assuming a balanced system the factor can be determined from expression (B9).

$$UF = 1 - \frac{Q_{pp} + Q_{hx}}{Q_{rec}}$$

where

Q_{hx} is the energy lost from the water in the heat exchanger (see A5)

Q_{pp} is the energy lost from the water in the connecting pipes (see A3)

Q_{rec} is the energy recovered from a shower (see A6)

$$UF = 1 - \frac{2l\pi r^2 \rho C_p (T_{drain} - T_{drain,out}) + (\rho C_p V_{hx} + M_{hx} C_{hx})(\frac{(T_{drain} + T_{drain,out} + T_{c,out} + T_c)}{4} - T_c)}{V \rho C_p \eta (T_{drain} - T_c)} \qquad \text{B5}$$

The temperature of preheated cold water ($T_{c,out}$) and waste water exiting the heat exchanger ($T_{drain,out}$) depends on the heat exchanger efficiency and the thermal mass flow rates. From the conservation of energy through the heat exchanger (i.e. the energy extracted is equal to energy absorbed) B6 is deduced.

$$(T_{c,out} - T_c) m_{pre} = m_{drain} (T_{drain} - T_{drain,out}) \qquad \text{B6}$$

m_{pre} and m_{drain} is the flow rate (W/K) of the preheated water and drainage through the heat exchanger respectively.

From the definition of efficiency it can also be deduced (i.e. energy transferred is equal to the energy absorbed).

$$(T_{c,out} - T_c) m_{pre} = \eta \left(T_{drain} - T_c\right) m_{drain} \qquad \text{B7}$$

Using B6 to eliminate $(T_{drain} - T_{drain,out})$ A3 becomes

$$Q_{pp} = l\pi r^2 \rho C_p (T_{c,out} - T_c) + l\pi r^2 \rho C_p (T_{c,out} - T_c) \frac{m_{pre}}{m_{drain}} \qquad \text{B8}$$

Using B7 to eliminate $(T_{c,out} - T_c)$ B8 becomes

$$Q_{pp} = l\pi r^2 \rho C_p \eta \ \left(T_{drain} - T_c\right) \ (\frac{m_{drain}}{m_{pre}} + 1) \tag{B9}$$

Factoring out the ¼ from A5 gives:

$$Q_{hx} = 0.25(\rho C_p V_{hx} + M_{hx} C_{hx})((T_{drain} - T_c) + (T_{drain,out} - T_c) + (T_{c,out} - T_c)) \tag{B10}$$

Using B6 to eliminate $(T_{c,out} - T_c)$ B10 becomes

$$Q_{hx} = 0.25(\rho C_p V_{hx} + M_{hx} C_{hx})((T_{drain} - T_c) + (T_{drain,out} - T_c) + \ \eta \ \left(T_{drain} - T_c\right) \ \frac{m_{drain}}{m_{pre}}) \tag{B11}$$

Making $T_{drain,out}$ the subject of B6 and using B7 to eliminate $(T_{c,out}$ - $T_c)$ B6 can be rewritten as:

$$T_{drain,out} = T_{drain} - (T_{c,out} - T_c) \frac{m_{pre}}{m_{drain}} = T_{drain} - \eta \ \left(T_{drain} - T_c\right) \tag{B12}$$

Using B12 to eliminate $T_{drain,out}$ from B11 the following is obtained:

$$Q_{hx} = 0.25(\rho C_p V_{hx} + M_{hx} C_{hx})(T_{drain} - T_c)(2 - \eta \ + \ \eta \ \frac{m_{drain}}{m_{pre}}) \tag{B13}$$

Using A6, B9 and B13 in the definition of Utilisation factor then:

$$UF = 1 - \frac{l\pi r^2 \rho C_p \ \eta(\frac{m_{drain}}{m_{pre}} + 1)\left(T_{drain} - T_c\right) + 0.25(\rho C_p V_{hx} + M_{hx} C_{hx}) \ (2 - \eta \ + \ \eta \ \frac{m_{drain}}{m_{pre}})\left(T_{drain} - T_c\right)}{V \rho C_p \eta \left(T_{drain} - T_c\right)} \tag{B14}$$

Cancelling out the common factor of $\left(T_{drain} - T_c\right)$ and noting that the volumes $l\pi r^2$, V and V_p are expressed in litres then:

$$\boxed{UF = 1 - \frac{1000 l\pi r^2 \rho C_p \ \eta(\frac{m_{drain}}{m_{pre}} + 1) + 0.25(\rho C_p V_{hx} + M_{hx} C_{hx}) \ (2 - \eta \ + \ \eta \ \frac{m_{drain}}{m_{pre}})}{V \rho C_p \eta}} \tag{B15}$$

The utilisation factor (B15) is now expressed in known quantities; provided $\frac{m_{drain}}{m_{pre}}$ is also known. This ratio varies with system type and may vary monthly.

For system A (balanced) the ratio in unity making B15 the same as that derived in A10.

$$\frac{m_{drain}}{m_{pre}} = 1 \qquad \text{B16}$$

For system B (unit only pre-warms the cold water supply to the shower) by considering the conservation of mass and energy of the shower water then:

$$\boxed{\frac{m_{drain}}{m_{pre}} = \frac{(T_h - T_c)}{\eta\ \left(T_{drain} - T_c\right)\ + (T_h - T_{mix})}} \qquad \text{B17}$$

All these parameters are known but vary monthly; hence a yearly average weighted value is calculated using the same weighting factors as those used to derive the yearly efficiency.

For system C (units only pre-warm the cold water supply to hot water tank or combi boiler) by considering the conservation of mass and energy of the shower water at the shower head.

$$\boxed{\frac{m_{drain}}{m_{pre}} = \frac{(T_h - T_c)}{(T_{mix} - T_c)}} \qquad \text{B18}$$

All these parameters are known but some vary monthly; hence a yearly average weighted value is calculated using the same weighting factors as those used to derive the yearly efficiency.

The formula derived (B15 to B18) will be used for SAP versions 2012 and onwards to calculate the utilisation factors.