SAP 2009 & 2012 - Calculation Methodology for electrically driven heat pumps

1 Introduction

This document describes the principles and key parameters used to assess the annual thermal performance of electrically driven heat pumps in SAP 2009 & 2012.

The heat pump annual performance calculations were first introduced in SAP 2005 via an Appendix Q procedure. Appendix Q is a procedure where technologies can be recognised in SAP between revisions that occur every three years. In SAP 2009 they were adopted and included in a newly expanded Appendix N which also specifies micro-cogeneration. Heat pumps were included in the same appendix as cogeneration because both technologies have an annual performance that is highly dependent on the plant heating capacity divided by the design heat loss of a dwelling. This is known as the Plant Size Ratio (PSR).

The annual assessment method is derived from EN15316-4-2:2008 and calculates a Seasonal Performance Factor (SPF) for a heat pump’s space heating duty and a separate SPF for hot water provision.

Part 2 of the following describes the main principles and parameters; part 3 describes definitions concerning heat pumps in SAP. Part 4 and 5 describe the main output and input parameters of EN15316-4-2 that are used in SAP 2009 & 2012. Appendix A provides more details including the equations that underlie the methodology.

2 Calculation Principles

The principle of this calculation procedure is to derive intermediate seasonal parameters for heat pumps using thermal performance measurements verified by independent laboratory tests following EN14511-2 and if required EN14825:2012 (50% load test). The intermediate seasonal parameters are:

a) Space heating Seasonal Performance Factor (SPF)[1]

b) Domestic hot water Seasonal Performance Factor (SPF)[2]

Note: a) is highly dependent on the Plant Size Ratio (PSR).

[1] Similar to the SEPEMO SPF_{H4} definition (Seasonal Performance factor and Monitoring for heat pump systems in the building sector), except that the SPF_{H4} definition includes hot water heating and back-up heating. The calculation method for the SAP space heating SPF calculates the useful heat input downstream of the buffer vessel, i.e. vessel heat losses reduce the SPF.

[2] Similar to the SEPEMO SPF_{H4} definition, the useful heat pump output applicable for both the SAP hot water SPF and SPF_{H4} definitions includes hot water cylinder heat losses – see Section 4.1.

A comparison between the definitions for the SEPEMO SPF_{H4}, the SAP space heating SPF and hot water heating SPF is provided in Appendix B.

To assess the overall thermal performance in terms of SAP, two other parameters need to be specified. These depend on the PSR and the designated hours of heating and are calculated according to Appendix N of SAP 2009/2012. The parameters are:

a) Fraction of the space heating requirement not supplied by the heat pump
b) The number of days that the heat pump is expected to operate longer than the standard SAP heating times.

A range of Space Heating Seasonal Performance Factors (SPF) is calculated by following the EN15316 annual performance method for a range of PSR values. These are then stored within the Product Characteristics Database (PCDB). SAP software undertakes linear interpolation based on the plant size ratio for the specific heat pump and dwelling being assessed.

The principle of the annual performance method follows the bin method specified in EN15316-4-2:2008. This involves the outside air temperatures being subdivided into bins of a certain temperature range, for example, the number of hours with a temperature within the range of 2ºC to 5ºC. For each temperature bin, the numerator and denominator of the Seasonal Performance Factor are calculated. These values are weighted by bin frequency and summed before dividing to give the Seasonal Performance Factor (SPF).

In certain conditions the heat pump might not satisfy the heating load or might be designed to provide only a proportion of the required heat. If this is the case, the fraction of heating required by a backup heating system is calculated according to Appendix N of SAP 2009/2012. This means the space heating SPF must exclude any backup heating. In contrast, if heat pump cannot satisfy the entire domestic hot water load, the backup energy required by an electric immersion heater is included in the domestic hot water SPF.

Heat pumps may operate more efficiently when running 24 hours/day or 16 hours/day as opposed to intermittently. The longer operation, however, has an energy penalty as it causes higher dwelling heat losses. This is accounted for by defining the designated hours of operation of a heat pump in the Product Characteristics Database (PCDB). The designated hours of heating are either a) 24 hours daily; b) 16 hours daily; c) 9 hours/day in the week and 16 hours/day at weekends (11 hours/day on average); or d) variable[3]. Appendix N of SAP 2009/2012 indicates the number of days a heat pump is expected to operate for 24 hours instead of 16 hours, or the number of days it is expected

[3] Variable is a special case where specific controls ensure that 16 hour operation or 24 hour operation is only required on certain days when the heat required cannot be met by operating for 9 hours/day or 16 hours respectively.

to operate for 16 hours instead of 9 hours, and depends on its designated hours of operation.

3 SAP heat pump definitions

The definition of heat pump service provisions within SAP may or may not include auxiliary space heating or water heating equipment, such as a specified hot water cylinder (by the manufacturer).

The four Service Provisions categories are:

i. Space and hot water all year
ii. Space and hot water in heating season only
iii. Space heating only
iv. Water heating only

An alternative system in SAP is selected by the assessor to meet any heating or domestic hot water service that is not provided by the heat pump.

3.1 Hot water storage vessel categories

The hot water storage vessel categories are:

Description of hot water vessel	**HW Vessel Category**
Integral hot water store	1
Separate cylinder whose minimum characteristics are specified in the SAP Product Characteristics Database (PCDB)[4]	2
Separate cylinder, characteristics not specified	3
None (heat pump service provision category iii)	4

An in-use factor (multiplier) is applied to the hot water SPF according to the service provided (See Table N7, Appendix N, SAP Technical Document).

An in-use factor of 0.95 is also applied for space heating operation.

3.2 Heat sources

Recognised heat pumps are grouped by heat source:

1. Ground (brine to water)
2. Water (water to water)

[4] For SAP 2005, heat pump listings are held within the SAP Appendix Q database.

3. Air (air to water)
4. Exhaust Air MEV (air to water)
5. Exhaust Air MVHR (air to air or air to water)
6. Exhaust Air Mixed (air to water)

Mixed source systems are reflected in the results of EN15316-4-2 by referencing a source temperature that is representative of the mixture.

Exhaust air heat pumps are linked to performance data held within the PCDB as appropriate for whole house mechanical extract ventilation (MEV) systems or mechanical ventilation with heat recovery (MVHR) systems. Mixed air exhaust heat pumps are linked to MEV system data held within the PCDB.

Ground-to-air, water-to-air and air-to-air heat pumps that are not part of the whole house ventilation system are currently excluded from SAP (i.e. those linked to warm air heaters).

3.3 Product size

The SPF of the heat pump depends on its maximum heat output (or capacity) compared to the maximum heat loss of the dwelling. This is known as the plant size ratio, or PSR. The PSR is defined as:

$$PSR = \frac{C_{out}}{Q_{loss} \times 24.2}$$

C_{out} (W) is the maximum heat capacity of the heat pump which will vary depending on the source temperature.
Q_{loss} (W/K) is the dwelling heat loss.

24.2K is the design temperature difference assumed when constructing Appendix N tables N3, N4 and N8. It is therefore important that the same temperature difference is used within SAP calculations.

3.4 Duration of heating

The standard SAP heating times are 9 hours a day in the week and 16 hours at weekends. Some heat pumps may be required to run longer to provide sufficient heat which must be accounted for in SAP. This is accounted for by calculating the resultant increase in the mean internal temperature of the dwelling.

The manufacturer specifies the heating times from the range listed below. The selected heating time is specified in the heat pump data record within the PCDB:

- 24 hours/day,
- 16 days/day,
- 11 hours /day (9 hours in the week and 11 at weekends)
- varying

Varying hours is a special case where the heat pump controls operation for longer than the SAP standard times in order to maintain satisfactory heating service during cold weather conditions. This could result in operating for 16 hours instead of 9 hours under cold but not severely cold conditions, or 24 hours instead of 16 or 9 hours under severely cold conditions. During mild weather the heat pump operates for the SAP standard times.

As of January 2013, all SAP PCDB heat pump data records have specified operating hours of 24 hours/day.

Tables N3 and N4 of SAP 2009/2012 show how the mean internal temperature is adjusted according to the heating hours indicated in the PCDB. The basis of these tables is shown in Appendix A of this document.

4 EN 15316-4-2:2008 Output Parameters

4.1 Seasonal performance factors

The following heat pump parameters are required by SAP to assess its thermal performance.

i) SPF for space heating
ii) SPF for domestic hot water service

SAP requires separate SPFs for heating and hot water production whereas EN15316-4-2:2008 combines them into one SPF.

SAP also requires the separation of the performance of the heat pump and any associated backup heating. Therefore, slightly different seasonal performance factors are defined for SAP purposes and are as follows:

a) Domestic hot water SPF

$$\eta_{hw} = \frac{\text{heat generated in the hot water}}{\text{Energy required including backup and any cylinder heat loss}}$$

The numerator only includes the heat supplied to the domestic hot water.

The denominator includes any backup heat required to generate the hot water and to keep any cylinder hot. Any auxiliary electricity used by other electronic components is also included.

In terms of EN15316-4-2:2008 variables this is:

$$\eta_{hw} = \frac{Q_{hw,gen}}{E_{hw} + E_{hw,st} + E_{hw,aux} + E_{hw,bk}}$$

$Q_{hw,gen}$	Hot water energy requirement
E_{hw}	Electricity input to heat pump for hot water-only
$E_{hw,st}$	Electricity input to cover storage losses
$E_{hw,bk}$	Electrical energy input to backup heater for hot water
$E_{hw,aux}$	Auxiliary electricity for hot water-only

The SAP hot water efficiency or SPF is defined as:

$$\eta_{hw,SAP} = \frac{Q_{hw,gen} + E_{hw,st}}{E_{hw} + E_{hw,st} + E_{hw,aux} + E_{hw,bk}}$$

To convert the EN15316-4-2:2008 SPF into a SAP SPF the following adjustment is required.

$$\eta_{hw,SAP} = \eta_{hw}(1 + E_{hw,st} / Q_{hw,gen})$$

$E_{hw,st}$ is set to the daily storage heat loss as indicated by the manufacturer from the lookup table in EN15316-4-2:2008.

$Q_{hw,gen}$ is set to the heat delivered to the hot water assuming number 2 tapping schedule of EN13203:part 2 (i.e. 5.485 kWh/day)

The SPF recorded in the PCDB includes this adjustment.

b)

b) Heating SPF

$$\eta_{sp} = \frac{\text{useful heat generated by heat pump excluding any backup}}{\text{energy required to produce the heat excluding any backup}}$$

The numerator only includes the useful heat generated by the heat pump.

The denominator excludes any backup heating but includes any auxiliary electricity used by other electronic components. The backup heating is removed from the definition because SAP handles this separately.

In terms of EN15316-4-2:2008 this is:

$$\eta_{sp} = \frac{Q_{sp,gen} - Q_{sp,bk}}{E_{sp} + E_{sp,aux}}$$

E_{sp}	Electricity input to heat pump for space heating only[5]
$Q_{sp,gen}$	Space heating requirement
$E_{sp,aux}$	Auxiliary electricity for space heating only
$Q_{sp,bk}$	Output of the backup heater for space heating

4.2 Backup heating

In SAP there is provision for three types of space heating:

- First main heating type – heat produced by the main heating system
- Second main heating type – heat produced by any alternative main system.
- Secondary heating – this represents any focal heating source (e.g. a living room fire)

Heat pumps may not be able to meet all the heating requirements of a main heating system because the dwelling's heat requirement exceeds the capacity of the heat pump on very cold days. To allow for this possibility, heat pumps may be installed with a backup heating system (e.g. a resistance heating element). If backup heating is integrated with a heat pump then the database record will include its efficiency and fuel source. If none are specified then direct electric heating is assumed.

4.3 Backup heating fraction

The backup heating fraction is the fraction of the space heating requirement not supplied by the main system. This fraction depends on, amongst others, the plant size ratio and duration of heating. It is more convenient to define plant heating fraction (1- backup fraction) as this can be tabulated for convenience (see Table A4). The details of the calculation are also shown in appendix A of this document.

The backup heating is only applicable to main heating systems because the secondary heating is related to focal heating and cannot be related to limiting the capacity of the heat pump.

Note: EN15316-4-2:2008 specifies its own backup fraction for space heating, but the method outlined in Appendix A was selected for consistency with other products recognised in SAP (e.g. micro-cogeneration).

[5] Which includes any buffer vessel heat losses, if applicable

5 EN15316-4-2:2008 Input parameters

The main input parameters used to derive the Seasonal Performance Factors for space heating and hot water are defined below:

The source temperature varies by heat pump source and is defined as follows:

a) Ground – T_{air} x 0.25806 + 2.837 subject to a minimum of 0ºC and maximum of 8ºC (Polynomial standard profile, F.2.1.3). T_{air} is the hourly outside air temperature (ºC).
b) Water – depends on individual system
c) Air– outside air temperature
d) Exhaust air – 20ºC
e) Mixed air and exhaust air – weighted average of c) and d)

The sink temperature varies with heat emitter type and is as follows:

a) Radiators: Design flow temperature of 55ºC, emitter temperature drop of 10ºC and emitter power law index of 1.2

b) Convectors: Design flow temperature of 45ºC, emitter temperature drop of 7.5ºC and emitter power law index of 1.2

c) Under floor heating: Design flow temperature of 35ºC, emitter temperature drop of 5ºC and emitter power law index of 1.2

d) Air (e.g. via MVHR): Design flow temperature of 35ºC, emitter temperature drop of 5ºC and emitter power law index of 1.0

The central heating flow temperature (heating curve calculation) for each mid-bin temperature is calculated according to (B1), EN15316-4-2:2008, which requires the internal room design temperature. If no weather compensator is specified the internal design temperature is set to the design flow temperature (e.g. 55ºC for radiators). This means the resultant daily flow temperature calculated using (B1) is equal to the design flow temperature every day in the heating season (e.g. for radiators the flow temperature is 55ºC throughout the heating season).

If a weather compensator is specified the internal design room temperature is set to 20ºC which means the resultant daily flow temperature varies from 20ºC on very mild days to the design flow temperature on very cold days (e.g. 55ºC for radiators).

For under floor heating it is assumed that weather compensating control cannot further improve heat pump performance and was therefore made ineffective if specified.

The space heating requirement is set to:

$$Q_{sp,gen} = \frac{24 \times DD(t_b) \times C}{(T_{o,d} - T_{i,d}) \times PSR}$$

$DD(t_b)$	Number of degree-days at base temperature (see table 1)
C	Heating capacity
$T_{o,d}$	Outside design temperature (-5ºC)
$T_{i,d}$	Inside design temperature (19.2ºC)
PSR	Plant size ratio

Table 1 Room and base temperatures used in EN15316-4-2:2008

Heating regime	Daily average inside design dwelling temperature ºC	Base temperature ºC
Variable	17.4	11.99
24 hours/day	19.2	13.78
16 hours/day	18.1	12.68
77 hours/week[6]	17.4	11.99

The hot water requirement is set to:

$$Q_{hw,gen} = 100 \times 50 \times 4.19 \times 365/3600$$

The assumed domestic hot water requirement is 100 litres/day warmed by 50K. The divisor converts from kJ to kWh. The specific heat capacity of water is taken as 4.19 kJ/Kg K.

The storage heat losses linked to the specified volume are shown below.

Table 2: Storage volume and heat loss

Nominal volume (litres)	Maximum heat loss (W)	Maximum heat loss kWh/day
30	31.3	0.75
50	37.5	0.9
80	45.8	1.1
100	54.2	1.3
120	58.3	1.4
150	66.7	1.6
200	87.5	2.1
300	108.3	2.6
400	125.0	3
500	129.2	3.1
600	158.3	3.8
700	170.8	4.1

[6] This is 9 hours/day in the week and 16 at weekends.

800	179.2	4.3
900	187.5	4.5
1000	195.8	4.7
1200	200.0	4.8
1300	208.3	5
1500	212.5	5.1
2000	216.7	5.2

The source of the climate data is the average monthly minimum and maximum air temperatures for the East Pennines (Bradford) from 1979-2008 (source Met Office Website) as this region is a good "UK average" and is used as such in SAP.

The monthly average daily minimum and maximum air temperatures were expanded into daily values for each month of year by using a normal distribution centred on each 30-year monthly value with a standard deviation of 2.5°C. This produces a good approximation of the daily maximum and minimum temperatures for each day over the past 30 years. The hourly temperatures were interpolated by assuming the maximum occurs at 3pm and the minimum at 6am using linear variation between the maximum and minimum.

The following figure and table shows the resultant air temperature distribution.

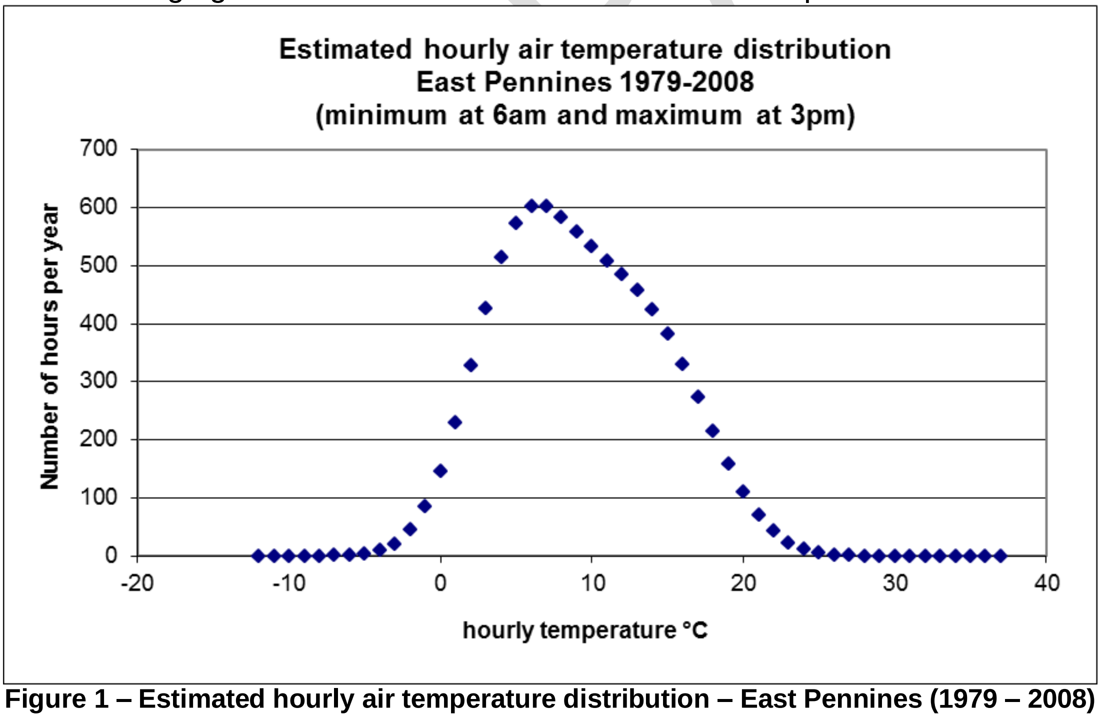

Figure 1 – Estimated hourly air temperature distribution – East Pennines (1979 – 2008)

Table 3 Estimated hourly air temperature distribution for East Pennines 1979-2008

Lower bin temperature range ºC	Number of hours
-12	0.000
-11	0.001
-10	0.006

-9	0.027
-8	0.106
-7	0.378
-6	1.210
-5	3.483
-4	9.019
-3	21.052
-2	44.365
-1	84.557
0	146.026
1	229.000
2	327.086
3	427.328
4	513.813
5	573.559
6	601.468
7	601.473
8	583.445
9	558.048
10	532.496
11	508.965
12	485.539
13	458.452
14	424.268
15	381.290
16	330.064
17	273.187
18	214.667
19	159.018
20	110.256
21	71.052
22	42.270
23	23.072
24	11.490
25	5.196
26	2.125
27	0.783
28	0.260
29	0.077
30	0.021
31	0.005
32	0.001
33	0.000
34	0.000
35	0.000
Total	8760

Appendix A - Plant heating fraction and days of longer heating duration

A1 Plant heating fraction

The plant heating fraction is defined as the fraction of heating that is supplied by the heat pump. It replaces the EN15316-4-2:2008 calculation to provide consistency with other technologies assessed within Appendix N of SAP and also since the EN15316 method applies to 24 hour heating only. The plant heating fraction depends on the Plant Size Ratio (PSR).

Calculate the appropriate base temperature to calculate T_{oL} according to (A8) and using the climate temperature calculate $DD(T_b)$, $\left[dd(T_b)\right]_{T_{oL}}^{T_{oW}}$ and $\left[N(T_o)\right]_{T_{oC}}^{T_{oL}}$ to calculate the plant heating fraction and hence the plant fraction as a function of the *PSR* according to (A9) or (A10) using the values tabulated below.

Table A1 Data required to calculate the primary heating fraction

Description	Symbol	Value
Base temperature (24 hr/day)	T_b	13.78 °C
Base temperature (16 hr/day)	T_b	12.68°C
Base temperature (77 hr/week)	T_b	11.99°C
Design outside temperature	T_{od}	-5°C
Inside temperature	T_{od}	19.2°C
Hours of heating per day	h	11[7], 16 or 24
Lowest external temperature that the plant can satisfy when operating at full load	T_{oL}	See (A8)
Plant size ratio	PSR	
Number of degree-days to base temperature	$DD(T_b)$	From climate data
Number of days when the external temperature is below lowest temperature that the plant can satisfy	$\left[N(T_o)\right]_{T_o=T_{oC}}^{T_o=T_{oL}}$	From climate data
Number of degree-days when the external temperature is below lowest temperature that the plant can satisfy	$\left[dd(T_b)\right]_{T_o=T_{oC}}^{T_o=T_{oL}}$	From climate data
Primary heating fraction	$f_{sp,np}$	See (9) or (10)
Plant heating fraction	f_{pl}	

[7] This is 9 hours in week and 16 hours at weekends, which averages 11 hours per week

For the case of varying heating hours, calculate the three lowest external temperatures at which the plant can satisfy the heating requirement when operating at 24, 16 or 11 hours per day respectively.

The number of hours the plant operates for extended hours is given in Table A2.

Table A2 Days of extended heating

Number of days (34 weeks)	Symbol	Variable heating hours	24	16	11
			hours/day		
operating at 16 instead 9 hours/day	$N_{16,9}$	$\frac{170}{243}\times\left[N(T_o)\right]_{T_o=T_{o,L16}}^{T_o=T_{o,L11}}$	0	170	0
operating at 24 instead 9 hours/day	$N_{24,9}$	$\frac{170}{243}\times\left[N(T_o)\right]_{T_o=T_{o,C}}^{T_o=T_{o,L16}}$	170	0	0
operating at 24 instead 16 hours/day	$N_{24,16}$	$\frac{68}{243}\times\left[N(T_o)\right]_{T_o=T_{o,C}}^{T_o=T_{o,L16}}$	68	0	0

The source of the weather data is the recorded average monthly minimum and maximum temperatures for the East Pennines (Bradford) from 1979-2008 as this region is a good "UK average" and is used as such in SAP.

The daily minimum and maximum were averaged to produce a daily temperature. The monthly mean temperature for the day is then expanded into means for each day of year. This was achieved using a normal distribution centred on each monthly value with a standard deviation of 2.5°C. It produces a good approximation for the average temperature for each day in the heating average over 30 years.

A2 Derivation of plant heating fraction

According to SAP 2005 box (81), the annual space heating requirement is:

$$DD(T_b) \times 0.024 \times Q_{loss} \qquad \text{A1}$$

Where $DD(T_b)$ is the number of degree-days in the heating season, T_b , is the base temperature and Q_{loss} is the specific heat loss of the dwelling in W/K.

Extending the logic to one day; on a day with external temperature of T_o the space heating requirement is:

$$\left[Q_{sp}\right]_{T_o} = \left[dd(T_b)\right]_{T_o} \times 0.024 \times Q_{loss} \qquad \text{A2}$$

Where $\left[dd(T_b)\right]_{T_o}$ means the number of degree-days for a day when the outside temperature is T_o .

From the definition of design heat loss:

$$dhl = (T_{id} - T_{od}) \times Q_{loss} \div 1000 \qquad \text{A3}$$

Using (A1) and (A2) to eliminate Q_{loss} gives:

$$\left[Q_{sp}\right]_{T_o} = \left[dd(T_b)\right]_{T_o} \times 24 \times dhl(kW) / (T_{id} - T_{od}) \qquad \text{A4}$$

And using the definition of plant size ratio (the capacity of the plant at the design temperatures divided by the design heat loss: Q_{nom} / dhl) to eliminate the design heat loss in (A4) then:

$$\left[Q_{sp}\right]_{T_o} = \left[dd(T_b)\right]_{T_o} \times \frac{24 \times Q_{nom}}{PSR \times (T_{id} - T_{od})} \qquad \text{A5}$$

The maximum heat that can be delivered is the plant capacity multiplied by the run hours $Q_{nom} \times h$ and therefore this will occur when the external temperature, T_{oL} , is such that:

$$h \times Q_{nom} = \left[dd(T_b)\right]_{T_{oL}} \times \frac{24 \times Q_{nom}}{PSR \times (T_{id} - T_{od})} \qquad \text{A6}$$

Rearranging gives:

$$\left[dd(T_b)\right]_{T_{oL}} = h \times PSR \times (T_{id} - T_{od}) / 24 \qquad \text{A7}$$

Finally, noting from the definition of degree-days that $\left[dd(T_b)\right]_{T_{oL}} = T_b - T_{oL}$ the outside temperature at which the plant operates at full load for the stated number of hours is therefore:

$$T_{oL} = T_b - h \times PSR \times (T_{id} - T_{od}) / 24 \qquad \text{A8}$$

Degree-days may be expressed as $\left[dd(T_b)\right]_{T_{o2}}^{T_{o1}}$ which means the sum of the number of degree days for each day of the heating season that has a temperature between T_{o1} and T_{o2}

The total heat requirement (unconstrained by capacity) is proportional to the number of degree-days and, on days colder than T_{oL}, the heat produced is limited to $(T_b - T_{oL})$ times the same constant of proportionality. Therefore, the heat requirement met by the heat pump, or the plant heating fraction, taking into account its limited capacity is:

$$f_{pl} = \frac{\left[dd(T_{b,h})\right]_{T_o = T_{oL}}^{T_o = T_b} + (T_b - T_{oL}) \times \left[N(T_o)\right]_{T_o = T_{oC}}^{T_o = T_{oL}}}{DD(T_b)} \qquad \text{A9}$$

$DD(T_b)$ is the usual degree-days over the heating season

$dd(T_b)$ is the degree-days summed between the warmest day and the day when the plant just meets the required demand

$N(T_o)$ is the number of days between the days when the plant cannot meet the demand (T_{oC} is the coldest temperature in the heating season).

For the case when the heating hours are extended automatically in cold weather to ensure the required demand can be met, then the plant fraction is:

$$f_{pl} = \{\left[dd(T_{b,11})\right]_{T_o=T_{oL11}}^{T_o=T_b} + \left[dd(T_{b,16})\right]_{T_o=T_{oL16}}^{T_o=T_{oL11}} + \left[dd(T_{b,L24})\right]_{T_o=T_{oL24}}^{T_o=T_{oL16}} + (T_{b,24} - T_{oL24}) \times \left[N(T_o)\right]_{T_o=T_{oC}}^{T_o=T_{oL24}}\} \div \{\left[dd(T_{b,11})\right]_{T_o=T_{oL11}}^{T_o=T_b} + \left[dd(T_{b,16})\right]_{T_o=T_{oL16}}^{T_o=T_{oL11}} + \left[dd(T_{b,L24})\right]_{T_o=T_{oC}}^{T_o=T_{oL16}}\} \qquad \text{A10}$$

The subscripts L11, L16 and L24 indicate the external temperature conditions as calculated in (A8) for 11, 16 and 24 hours/day heating. (T_{oC} is the lowest temperature in the climate record over the thirty year period 1979-2008).

Table A3 Days at longer heating duration

Weekday/weekend heating hours	*Number of days operating at the number of hours indicated by the subscript instead of the SAP standard hours indicated by the second subscript*		
	$N_{16,9}$	$N_{24,9}$	$N_{24,16}$
24/24	0	170	68
16/16	170	68	0
11/16	0	0	0
Varies	see table A4	see table A4	see table A4

Table A4 Look-up table for heating fraction and extra days at longer heating duration

Plant size ratio for design temperature difference of 24K	*Plant heating fraction for the weekday/weekend heating hours (f_{pl})*				*Number of days operating at the number of hours indicated by the subscript instead of the SAP standard hours indicated by the second subscript*		
	24/24	*16/16*	*9/16*	*Variable*	$N_{16,9}$	$N_{24,9}$	$N_{24,16}$
0.00	0%	0%	0%	0%	0	170	68
0.05	16%	13%	9%	16%	0	169	68
0.10	32%	24%	19%	31%	5	158	63
0.15	46%	36%	27%	45%	1	152	61
0.20	60%	47%	36%	59%	8	143	57
0.25	72%	57%	43%	70%	2	135	54
0.30	81%	66%	51%	80%	10	127	51
0.35	88%	73%	58%	87%	20	99	40
0.40	94%	80%	65%	93%	29	88	35
0.45	97%	86%	71%	97%	40	77	31
0.50	99%	91%	76%	99%	31	65	26
0.55	100%	94%	81%	100%	41	54	21
0.60	100%	97%	85%	100%	30	43	17
0.65	100%	98%	89%	100%	51	20	8
0.70	100%	99%	91%	100%	36	15	6
0.75	100%	100%	94%	100%	40	10	4
0.80	100%	100%	95%	100%	24	6	3
0.85	100%	100%	97%	100%	27	4	2
0.90	100%	100%	98%	100%	15	1	0
0.95	100%	100%	99%	100%	15	0	0
1.00	100%	100%	99%	100%	14	0	0
1.05	100%	100%	100%	100%	7	0	0
1.10	100%	100%	100%	100%	6	0	0
1.15	100%	100%	100%	100%	3	0	0
1.20	100%	100%	100%	100%	2	0	0
1.25	100%	100%	100%	100%	1	0	0
1.30	100%	100%	100%	100%	1	0	0
1.3 or more	100%	100%	100%	100%	0	0	0

Appendix B – SEPEMO SPF_{H4}

This appendix shows the relationship between the SEPEMO SPF_{H4} and the SAP SPF for space heating and hot water, enabling the conversion of SAP SPF values into SPF_{H4} values. The appendix is restricted to systems without a buffer vessel.

SEPEMO defines the Seasonal Performance Factor H4 as:

$$SPF_{H4} = \frac{Q_{H\_hp} + Q_{W\_hp} + Q_{HW\_bu}}{E_{S\_fan/pump} + E_{HW\_hp} + E_{bt\_pump} + E_{HW\_bu} + E_{B\_fan/pump}}$$

$E_{B\_fan/pump}$ is the electrical consumption of the equipment (e.g. pumps/fan) that distributes heat throughout the building

E_{bt_pump} is the auxiliary electrical consumption related to delivering heat from the heat pump to the heat emitter system

E_{HW_bu} is the energy used by the back-up heater(s) for heating and hot water

E_{HW_hp} is the electrical consumption of the heat pump to produce heating and hot water

$E_{S\_fan/pump}$ is the auxiliary consumption related to delivering heat from the external heat source to the heat pump.

Q_{H_hp} is the heat produced by the heat pump for space heating

Q_{HW_bu} is the heat produced for space heating and hot water by the back-up heater

Q_{W_hp} is the heat produced for domestic hot water by the heat pump

For a heat pump system without a buffer vessel an equivalent SPF_{H4} may be calculated using SAP SPF values from:

$$SPF_{H4} = \frac{Q_{H,req} + Q_{W,req} + Q_{W,st}}{\frac{f_{H\_hp} \times Q_{H,req}}{0.95 \times \eta_{sp}} + \frac{(Q_{W,req} + Q_{W,st})}{U_{W,F} \times \eta_{hw,SAP}} + \frac{(1 - f_{H\_hp}) \times Q_{H,req}}{\eta_{sp,bu}} + E_{B\_fan/pump}}$$

$E_{B\_fan/pump}$ is the electrical consumption of the central heating pump (SAP table 4f) or fans distributing heat around the dwelling (see SAP Table 4g and Table 4h)

f_{H_hp} is the fraction of heating supplied by the heat pump (See Table A4), which varies with the plant size ratio and heating duration

$Q_{H,req}$ is the annual heat requirement of the dwelling

$Q_{W,req}$ is the annual hot water requirement of the dwelling at the tapping outlet from the hot water cylinder.

$Q_{W,st}$ is the annual standby heat loss of the DHW cylinder

$U_{W,F}$ is an in-use factor applied by SAP to the hot water test data (see SAP specification Table N7)

0.95 is the in-use factor applied by SAP to the space heating efficiency.

η_{sp} is the SAP SPF for space heating recorded in the Product Characteristics Database. Note: A range of values are recorded at difference Plant Size Ratios (PSRs)

$\eta_{sp,bu}$ is the efficiency of the back-up space heater.

$\eta_{hw,SAP}$ is the SAP SPF for hot water production recorded in the Product Characteristics Database