Calculation Method: CALCM:01

SAP REVISED HEAT PUMP PERFORMANCE METHOD

Issue 1.2

DOCUMENT REVISIONS

Documents will be revised by issue of updated editions or amendments. Revised documents will be posted on the website at www.ncm-pcdb.org.uk/sap.

Technical or other changes which affect product recognition requirements (for example) will result in a new issue. Minor or administrative changes (e.g. corrections of spelling and typographical errors, changes to address and copyright details, the addition of notes for clarification etc.) may be made as amendments.

The issue number will be given in decimal format with the integer part giving the issue number and the fractional part giving the number of amendments (e.g. Issue 3.2 indicates that the document is at Issue 3 with 2 amendments).

Users of this document should ensure that they possess the latest issue.

DOCUMENT REVISION LOG

DATE	VERSION NO.	AMENDMENT DETAILS	APPROVED BY
06/10/16	1.0	First issue	PD
03/08/17	1.1	Amendment to equations 6, 16 and 26 in relation to calculating effect of part load operation. Clarification of minimum modulation rate data requirements. General clarifications throughout.	WG
05/09/17	1.2	Added $\Delta\theta_{min}$ definition in Section 3.2.4.	WG

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1. INTRODUCTION

The purpose of this document is to specify a revised heat pump annual calculation method for use in SAP calculations (2009 and later versions). SAP is the UK's National Calculation Methodology for energy rating of dwellings. This revision is required because of changes to test requirements arising from Ecodesign regulations (No. 811/2013 and 813/2013).

Heat pump annual performance calculations were first introduced in SAP 2005 via a SAP Appendix Q procedure. In SAP 2009 they were adopted and included in a newly expanded SAP appendix (Appendix N) which includes provision for heat-led 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).

This heat pump annual performance calculation method was derived from EN15316-4-2:2017 and calculates a Seasonal Performance Factor (SPF) for a heat pump's space heating duty at a range of PSR values (0.2 to 2.0; for SAP 2016 this is 0.2 to 3.0) and a separate SPF for hot water provision.

For the avoidance of doubt, and in the context of this document, SPF refers to estimated annual performance and differs from Seasonal Coefficient of Performance (SCOP)[1], which is an alternative method of estimating annual efficiency. The SCOP method typically assumes that the nominal heat pump output matches the dwelling heat loss, which is not appropriate for SAP.

Whilst this document refers to "SPF", all calculated values subsequently transferred to the Product Characteristics Database (PCDB) are converted to efficiency values, expressed as percentage.

[1] Used within Ecodesign regulations via EN14825. Both EN14825 and this method use Coefficient of Performance (COP) test data at specific test conditions.

Note: Equations with black reference numbers are reproduced directly from EN15316-4-2:2017. Therefore, equation numbering for these equations is not necessarily sequential.

2. BACKGROUND

2.1 PREVIOUS SAP CALCULATION METHOD PRINCIPLES

To assess heat pump performance for SAP purposes, three parameters other than space and hot water heating SPF need to be specified. These depend on the PSR and the heating operating hours and are calculated according to the previous annual performance heat pump method within Appendix N of SAP 2009 and SAP 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
c) The running time (in hours) of the heat pump

Parameter a) is obtained from SAP 2012 Table N9 (SAP 2009 Table N8) and parameter b) from SAP 2012 Table N4 or N5 (SAP 2009 N3 and N4).

A range of space heating Seasonal Performance Factors (SPF) are calculated by following the EN15316-4-2:2008 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 PSR for the specific heat pump and dwelling being assessed.

The principle of the previous annual performance method follows a bin method as specified in EN15316-4-2:2008. This involves the outside air temperatures being subdivided into bins of a certain temperature range. The temperature bins are weighted by bin frequency to determine 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 back-up (direct-electric) heating system is calculated according to Appendix N of SAP (2009 and 2012 previous method). This means the space heating SPF must exclude any back-up heating (this aspect is changing in the revised calculation method, described in this document, so that direct-electric back-up heating is incorporated within the SPF). In contrast, if the heat pump cannot satisfy the entire domestic hot water load, the back-up energy required by an electric immersion heater is included in the domestic hot water SPF.

Heat pumps may operate more efficiently when operating 24 hours/day or 16 hours/day as opposed to intermittently. However, the longer operation has an energy penalty (within the SAP calculation, not the SPF calculation) since 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[2]. Appendix N of SAP (previous method) also 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 to operate for 16 hours instead of 9 hours, with respect to the designated operating hours.

2.2 CHANGES TO SAP CALCULATION METHOD

SAP 2012 was published in October 2013 using the same heat pump annual calculation method used in SAP 2009. The introduction of Ecodesign regulations (811/2013 and 813/2013) has meant that extensive testing requirements (EN14825 and EN16147[3] for electrically-driven heat pumps) have been introduced for heat pumps. These requirements differ from (full-load) EN14511 Standard Rating Condition tests, which were frequently undertaken throughout Europe to demonstrate instantaneous performance and used for the purpose of entry in the SAP PCDB under the previous calculation method.

The European Commission requested that CEN develop a suite of European Standards capable of assessing the energy performance of buildings. The overarching standard is ISO 52000-1. The standard EN15316-4-2:2017 is an updated component standard and includes the ability to accept Ecodesign test data. The standard introduces a number of

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[2] Variable is an idealised control method for the purposes of the calculation method, see Section 3.1.5.

[3] For combination heat pumps and hot water only heat pumps

technical improvements, in particular the facility to undertake hourly calculations using EN14825 test data arising from Ecodesign regulations (No. 811/2013).

3. CALCULATION INPUTS

3.1 UNCHANGED CALCULATION INPUTS

3.1.1 Heat pump category

Recognised heat pumps are grouped by heat source:

1) Ground (Indirect/Closed-loop: Brine to water)
2) Air (air to water)
3) Exhaust Air MEV (air to water)[4]
4) Exhaust Air MVHR (air to air or air to water)[5]
5) Exhaust Air Mixed (air to water)[6]
6) Water (Direct/Open-loop: Ground water to water)
7) Water (Direct/Open-loop: Surface water to water)
8) Solar-assisted

For all categories, except Category 2), EN14825 test results are produced at only one source temperature. Therefore, a different interpolation procedure to that described in EN15316-4-2:2017, Section 6.7.3 is necessary. This interpolation is based on the correction factor in Equation *D4* of EN15316-4-2:2017.

For category 1), the source temperature ($\vartheta_{gen,in}$) assumption is unchanged from the previous method and is determined using the following equation[7]:

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[4] Note: For validity of this calculation method, the heat pump installation must exclusively satisfy the "System 3" definition provided in Building Regulations – Approved Document Part F (Ventilation), i.e. no supplementary ventilation systems should be required to satisfy a dwelling's ventilation requirements.

[5] Note: For validity of this calculation method, the heat pump installation must exclusively satisfy the "System 4" definition provided in Building Regulations – Approved Document Part F (Ventilation), i.e. no supplementary ventilation systems should be required to satisfy a dwelling's ventilation requirements. Air to air variants are not recognised by this calculation method.

[6] Note: Footnotes 4 or 5 apply as appropriate

[7] Equation developed from air vs brine temperature relationship presented in EN15316-4-2:2008, but amended to UK conditions during the development of previous calculation method.

$$\vartheta_{gen,in} = T_o \times 0.25806 + 2.8387 \quad (°C) \quad \textbf{(1)}$$

This is subject to a maximum source temperature of 8ºC and a minimum of 0ºC. "T_o" is the outside air temperature (dry bulb).

For category 6), where water is extracted from the ground and re-injected into the ground or discharged at the surface, the source temperature ($\vartheta_{gen,in}$) is assumed to be constant and equal to the SAP annual average air temperature.

For category 7), where water is extracted from surface water, such as rivers and lakes, it is assumed that this extraction does not substantively effect the average temperature of the water volume, thus it must have sufficient thermal capacity. The source temperature ($\vartheta_{gen,in}$) is taken as the SAP monthly average air temperature.

The treatment of heat pumps that extract heat from sea water has not been defined.

For category 8), a characteristic equation for the source temperature ($\vartheta_{gen,in}$) has not yet been devised.

The following heat pump categories are not currently recognised by SAP: Ground-to-air, water-to-air and air-to-air heat pumps.

Explicit provision for Category 3) - Exhaust Air Mechanical Extract Ventilation (MEV) heat pumps is not provided in EN15316-4-2:2017, but the revised SAP method provides recognition using a constant source temperature of 20°C[8] (as used in the previous method).

Similarly, for Category 4) - Exhaust Air Mechanical Ventilation and Heat Recovery (MVHR) heat pumps, no explicit method is provided in EN15316-4-2:2017, but the revised

[8] Tested in accordance with SAP test method: 'Test method for centralised Mechanical Extract Ventilation (MEV) system packages'. Fan power to be determined when the heat pump package has no heat demand, but is otherwise active.

SAP method provides recognition using a constant device inlet temperature of 20°C[9] (as used in the previous method).

Category 5) - Exhaust Air Mixed heat pumps may utilise either an MEV or MVHR configuration for air supply to the Evaporator in conjunction with an external air supply. In this case the source temperature is determined for each calculation interval as a proportion of the airflow volume passing through the MEV or MVHR (at 20°C) and volume ducted from outside (using the external air temperature for the hourly calculation interval). The relative flow volume proportions may vary in accordance with dwelling heat load (incorporating hot water demand) or external temperature. In this case, this variation must be defined by the manufacturer during the application process and an hourly source temperature profile will be devised.

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

The running hours for all heat pump categories are included in the PCDB data record and are dependent on the plant size ratio. For Exhaust Air heat pumps (Categories 3) - 5)), the heat pump and mechanical ventilation system are tested together and so the energy consumption of the central ventilation fan while the heat pump is operating is included in the SPF, but not when it is not. Therefore, testing of the mechanical extract fan power only is required.

Category 3) - 5) heat pumps may require a higher dwelling air flow rate through the ventilation system when operating than would apply without the heat pump. The SAP calculation allows for this via a separate calculation, SAP Equation N4, which replaces data from SAP Table 4f.

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[9] Tested in accordance with SAP test method: 'TESTM:01 - SAP 2012 Test method for Centralised Mechanical Supply and Extract Ventilation System Packages with heat recovery used in a single dwelling'. MVHR efficiency and fan power to be determined when the heat pump package has no heat demand, but is otherwise active.

For heat pumps a set of intermediate PSR-dependent results (SAP Table N2, see: APPENDIX C – SAP TABLE N2), are provided for three sink temperatures, and in the case of an exhaust air heat pump, for two or three air flow rates at which the combined system was tested. The latter requires an additional linear interpolation of the data based on the air flow rate through the ventilation system in litres per second calculated by SAP Equation *(N1).*

$$\text{Throughput (l/s)} = \text{volume (m}^3\text{)} \times \text{system throughput (ach/hour)} \div 3.6 \qquad (N1)$$

The SAP calculation process for Category 3) to 5) heat pumps follows these steps:

1) If the ventilation throughput for the dwelling is greater than the highest value in the database record for the heat pump, use the intermediate values at the highest air flow rate in the database record.

2) If the throughput lies within the range of values in the database record, use the intermediate results for the applicable throughput by linear interpolation.

If the throughput is less than the lowest value in the database record, calculate a heat pump over-ventilation ratio (R_{hp}) as the lowest rate in the database record in the database record (l/s) divided by the required dwelling rate (l/s); otherwise set the ratio to 1. When the ratio exceeds 2 the data is invalid for the dwelling and when it is above 1 but less than or equal to 2 use the intermediate results for the lowest value in the database record. Further calculations are required using the over-ventilation ratio as set out in APPENDIX A – EXHAUST AIR HEAT PUMP OVERVENTILATION. The interpolation for PSR is undertaken first, followed by the interpolation for air flow rate.

3.1.2 Service Provisions

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

3.1.3 Hot water vessels

The hot water storage vessel categories are:

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

An in-use factor (multiplier) is applied to the calculated hot water SPF according to the service provided (See Table N7, Appendix N, SAP 2012 specification), i.e. HW Vessel Categories 1 - 3[10].

3.1.4 Synchronised control for hot water heating

The primary operation of any supplementary heater (electric immersion) must be controlled by the heat pump controller. This ensures that the timing of supplementary heating is coordinated with the heat pump to prevent unnecessary operation of the supplementary heater. Local occupant control to provide additional boosting may be provided, but this should automatically reset once the required hot water temperature is achieved in the vessel, requiring further manual intervention for any subsequent boosting.

Manufacturers must supply a full installation and commissioning manual including details of how the synchronised control of the supplementary heater is to be set. The manual

[10] An in-use factor of 0.95 is applied to space heating operation within the previous method used for SAP 2009 and 2012. It has been retained in this revised method.

must provide full details of any manual override functions for boosting hot water, and the method employed to ensure that it is not left in this mode inadvertently.

If evidence is unavailable, it will be assumed that hot water provision is provided solely by the supplementary system, e.g. a direct electric immersion heater.

3.1.5 Operating hours

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

In principle, the heat pump manufacturer may specify the heating times from the range listed below. The selected heating time is specified in the heat pump data record within the PCDB, the options are:

- 24 hours/day
- 16 hours/day
- 11 hours/day (equivalent to the SAP standard heating hours of 9 hours for weekdays and 16 hours for weekends)
- Variable

Variable is an idealised control method for the purposes of the calculation method and uses specific controls that ensure that 16 hour operation or 24 hour operation is only required on certain cold days when the heat required cannot be met by operating for 9 hours/day or 16 hours/day respectively. During mild weather the heat pump operates for the SAP standard heating times[12].

As of August 2016, all SAP PCDB heat pump data records have specified operating hours of 24 hours/day. However, as a result of the calculation method changes defined in this document, all SAP PCDB heat pump data records calculated using the method will have variable operating hours assigned by default[11].

Appendix N of SAP 2009 and 2012 shows how the mean internal temperature is adjusted according to the heating hours indicated in the PCDB.

Adding separate weekday and weekend profiles to this calculation method was considered, but this would lead to it being sensitive to when the weekend occurs in relation to the weather data, requiring the method to be run seven times with the same weather data, but with January 1st being a different day of the week.

For the revised calculation method, the 11 hour/day option, which reflects standard SAP operating hours (16 hours at weekends and 9 hours on weekdays for Zone 1), is defined for the purposes of the revised calculation method as occurring from 7:00-9:00 and 14:00-23:00 seven days a week[12]. The 16 hour/day operating option is defined as 7:00-23:00. There is no space heating from June to September.

The operational hours for water heating (i.e. times when any hot water vessel can be heated) are the same as for space heating, but continue in the summer months.

3.1.6 Plant Size Ratio

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:

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[11] The first heat pump to be processed via this calculation method occurred in October 2016.

[12] Actual SAP standard heating operational hours are:

- 07:00-09:00 and 16:00-23:00 on weekdays for Zone 1
- 07:00 - 09:00 and 18:00-23:00 on weekdays for Zone 2
- 07:00 - 23:00 on weekends for Zone 1
- 07:00 - 09:00 and 14:00-23:00 on weekends for Zone 2

$$\mathbf{PSR} = \frac{\phi_{dgn}}{(\mathbf{H} \times \mathbf{24.2})} \quad (2)$$

Where:

ϕ_{dgn} (W) is the maximum heat capacity of the heat pump under design conditions[13]

H (W/K) is the dwelling specific heat loss

24.2K is the design temperature difference between inside and outside of the dwelling.

The SAP PCDB allows for performance data recording at seven different PSR values. The default database entries[14] for heat pumps are 0.2, 0.5, 0.8, 1, 1.2, 1.5 and 2, but can vary. The SAP 2016 PCDB allows for nine different PSR values, where 2.5 and 3.0 will be added to the default range.

3.1.7 Design flow temperature

Since inception of the heat pump calculation method, data records have been determined for three design flow temperature classes: 35ºC, 45ºC and 55°C, in principle irrespective of emitter type - see Section 3.2.4. Other flow temperature classes can be enabled; 58°C (default temperature) and 65°C will be added for SAP 2016.

3.1.8 Weather compensation

If weather compensation is indicated by the manufacturer as present, this will be accounted for within the calculation of space heating SPF, provided that manufacturers confirm its default presence without necessitating an optional control device. If

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[13] Determined using Equations (33) or (34) with a source temperature of -4.7°C and sink temperature of 35°C, 45°C, 55°C, 58°C or 65°C for values with subscript “X”; values with subscript “cld” use EN14825 test condition “A” values, those with “D” use test condition “D” values.

[14] SAP 2012 states: “*Where the PSR is greater than the largest value in the data record, an efficiency* [converted from SPF] *may be obtained from linear interpolation between that at the largest PSR in the PCDB data record and an efficiency of 100%* [SPF = 1.0], *where the PSR is <u>four</u> times the largest PSR in the PCDB data record. The interpolated efficiency is the reciprocal of linear interpolation between the efficiency reciprocals*”. For SAP 2016, the multiplier will be reduced to two times the largest PSR.

confirmation is not possible, weather compensation will not be included in the calculation of space heating SPF.

During SAP assessments, assessors must ensure that the control (as specified by the heat pump manufacturer) is fitted as part of the installation; it must also be permanently enabled.

SAP defines weather compensation as *“A device, or feature within a device, which maintains the temperature inside the building by sensing and limiting the temperature of the water circulating through the heat generator and heat emitters in relation to the temperatures measured outside the building”.* For the avoidance of doubt, this means that restricting the maximum temperature of return (heat pump inlet) water, but not the maximum temperature of flow (heat pump outlet) water, will not satisfy the definition.

3.2 CHANGED CALCULATION INPUTS

The revised calculation method uses all default EN15316-4-2:2017 inputs unless expressly stated otherwise. It follows an hourly calculation method (Path B), which enables the use of part-load data (from EN14825/Ecodesign regulations). Path A uses only full-load data and is not used.

The following inputs are required in order to use the standard and were determined for the purpose of SAP.

3.2.1 Weather data

Hourly external temperatures ($T_{o,h}$) are sourced from CIBSE Guide J and are based on a Test Reference Year for Leeds (location close to the East Pennines, which is used as the basis of SAP calculations; see SAP 2009 - Table 8/SAP 2012 - Table U1). These values were normalised for consistency with SAP monthly average temperatures as:

$$T_{o,h} = T_{o,h}(Leeds) - (\bar{T}_o(Leeds) - \bar{T}_o(SAP)) \quad \text{(°C)} \qquad (3)$$

The subscript "h" denotes hourly and the vinculum (over bar) denotes monthly average.

The months January to November showed reasonable agreement with SAP monthly average values and required less than 1ºC correction. The average for December was 2.2ºC warmer for CIBSE Leeds data when compared to SAP 2009 monthly average temperatures, which are supplied by the Meteorological Office for the East Pennines Region from 1992 to 2011.

SAP 2009 and SAP 2012 feature different average UK temperature data. The mean temperature during the heating season is 7.28ºC using SAP 2009 data and 7.44ºC using SAP 2012 data. A sensitivity analysis indicated that using SAP 2012 climate data would result in a calculated Seasonal Performance Factor (space heating or water heating) that was a maximum 0.6% lower than SAP 2009 climate data and require a 0.1% point increase in the back-up fraction. Therefore, SAP 2012 climate data will be used to calculate SPFs for both SAP 2009 and 2012.

3.2.2 SAP 2009/2012 implementation

A revised *SAP Table N5 (Additional days at longer heating duration for variable heating)* (N4 for SAP 2009) that matches the revised climate data is given in Appendix B. Since the magnitude of the proposed changes to the table are not large, and the existing table is embedded within SAP software, this table will only be implemented in the SAP 2016 revision.

The previous heat pump calculation method varied the back-up (direct-electric) heating fraction with PSR, as specified in SAP 2012 Table N9 (N8 in SAP 2009). This approach was independent of heat pump capacity and did not consider the interaction with hot water load - see SAP specification for further details.

This revised heat pump calculation method includes the interaction of space and hot water heating loads on an hourly basis; the back-up fraction will therefore vary with PSR and thermal capacity. For this reason, this revised method calculates the back-up fraction for each heat pump data record at each PSR value.

From SAP 2016 onwards, the efficiency (SPF) recorded in the PCDB will include the back-up fraction explicitly - see Section 3.2.12.

For the purposes of implementation within SAP 2009 and 2012, where a back-up fraction will automatically be applied by SAP software (via Table N9 for SAP 2012 and N8 for SAP 2009), the following equation will apply to the calculated space heating efficiency in order to correct it[15]. This will not be necessary in future SAP revisions, where Table N9 will be restricted to cogeneration applications.

The annual space heating efficiency determined for a PSR of 0.2 and 0.5 (back-up fraction is zero for all other standard PSRs in SAP 2009 and 2012, so correction is unnecessary) should be corrected using the following equation[16]:

$$\eta_{H,SAP2012} = \frac{\eta_H \times (1 - f_{H,bu,SAP2012})}{1 - 0.01 \times \eta_H \times (f_{H,bu,SAP2012})} \quad (\%) \qquad (4)$$

Where:

$f_{H,bu,SAP2012}$ is the fraction of space heating provided by the back-up according to SAP 2012 Table N9 (Table N8 in SAP 2009)

η_H is the space heating annual efficiency calculated by this calculation method

$\eta_{H,SAP2012}$ is the scaled space heating efficiency recorded in PCDB for SAP 2009 and 2012 calculations (only), which allows for SAP software's automated application of a (now incorrect) back-up fraction

3.2.3 Space heating load

To determine the hourly energy requirements ($Q_{H,gen,out}$) for a specific PSR for an example dwelling in accordance with the SAP specification:

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15 This means that comparing calculated efficiencies held in the PCDB using the previous and revised calculation methods will not be directly possible. Note: Efficiency is converted from SPF for PCDB entry.

16 NOTE: The space heating annual efficiency (η_H) entering the equation is capped at 210% when the PSR = 0.2.

$$Q_{H,\text{gen,out}} = \frac{24 \times (T_b - T_o) \times \phi_{dgn} \times t_{ci}}{h \times PSR \times \Delta T_{d,d}} \qquad \textbf{(kWh)} \qquad \textbf{(5)}$$

h is the hours of operation per day (24, 16, 11 or for variable hours see below)

T_b is the daily mean internal temperature of the dwelling minus the ratio of useful heat gains to heat losses. A monthly gains/loss ratio value is used for this purpose since it varies throughout the year and according to heating operation hours. The daily mean internal temperature is taken as the monthly value calculated by SAP. Heat losses and useful heat gains are sourced from an example SAP calculation for a dwelling with a medium level of insulation and medium thermal mass[17].

t_{ci} is the calculation interval in hours (1 hour)

T_0 is the daily average outside air (dry bulb) temperature (ºC)

$\Delta T_{d,d}$ is the temperature difference between the inside and outside of the dwelling under design conditions.

ϕ_{dgn} is the heat output under design conditions [at -4.7°C using equations (33) or (34)]

The hourly heating load is based on the daily outside temperature, and not the hourly temperature, because the dwelling's thermal mass dampens the response. Using an hourly variation without the effect of the thermal mass of the building is less realistic than using the daily average.

Note: When variable hours are selected the hours of heating per day are calculated for each calculation interval as follows:

Calculate the lowest outside temperature (T_{oLi}) that can be met when operating for 24, 16 and 11 hours respectively without requiring system back-up heating.

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[17] A detached house (100m^2) with a heat loss parameter of 2.72 W/K per m² and a thermal mass parameter of 245.5 kJ/K per m²

$$T_{oLi} = T_b - h_1 \times min(PSR, 1/f) \times \Delta T_{d,d}/24 \quad (°C) \quad (6)$$

Where the subscript (i) is replaced by 24, 16 and 11 hours and '*f*' is the emitter intermittency factor (see Table 1).

Set the heating operational hours for calculation interval according to:

$h = 24$ when $T_o < T_{oL16}$

$h = 16$ when $T_{oL16} \leq T_o < T_{oL11}$

$h = 11$ when $T_o \geq T_{oL11}$

3.2.4 Flow temperatures

Heat pump performance is affected by the flow temperature, often referred to as the sink temperature, which varies within each calculation interval. For hot water heating service flow temperatures, see Section 3.2.7. For space heating service, the flow temperature (in °C) is calculated from:

$$\vartheta_{gen,out}(t) = T_{d,d} + \left(\overline{T_{E,d}} - T_{d,d}\right)\left[\frac{24f(T_b - T_o)}{h\Delta T_{d,d}}\right]^{1/n} + \frac{24f(T_b - T_o)}{h\Delta T_{d,d}}\frac{\Delta T_{E,d}}{2} \quad (7)$$

The flow temperature is subject to a minimum of $\Delta\theta_{min}$ above $T_{d,d}$.

Note, this equation is similar to the equation in EN15316:4.2:2008 Appendix B, but with an extra factor "24f/h" introduced for intermittent heating.

n	is the power law index (see Table 1 values)
$T_{d,d}$	is the temperature of the dwelling under design conditions[18]
$\overline{T}_{E,d}$	is the average emitter temperature[19] under design conditions
$\Delta T_{E,d}$	is the water temperature difference across the emitter's inlet and outlet under design conditions

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[18] Derived using SAP as 19.5°C (24hr/day), see Footnote 17, where the Living Area fraction = 0.3

[19] Also referred to as Mean Water Temperature

$\Delta\theta_{min}$	is a global minimum temperature difference applied throughout the calculation method – default 5K.
$\vartheta_{gen,out}$	is the heat pump flow (outlet water) temperature
f	is the emitter intermittency factor (see Table 1)
h	is the number of hours of heating per day

Emitter Type	Radiators				Fan Convectors			Underfloor heating		
Design flow temperature	65ºC	58ºC	55ºC	45ºC	55ºC	45ºC	35ºC	55ºC	45ºC	35ºC
Temperature difference	9.29K	8.29K	7.86K	6.43K	7.85K	6.42K	5K	7.85K	6.42K	5K
Power law index (n)	1.2	1.2	1.2	1.2	1.0	1.0	1.0	1.0	1.0	1.0
Intermittency factor, f	1.0 for 24-hour heating, otherwise $0.8\dot{3}$ $(1 \div 1.2)$									

Table 1 – Emitter design parameters

A sensitivity assessment was conducted to determine the impact of emitter power law index upon calculated SPF. An index number increase from 1.0 to 1.2 resulted in a 2.5% reduction in SPF. Whilst this is not particularly significant, to minimise complexity of options, the worst-case SPF is to be used. Therefore, this calculation method associates the non-greyed emitter parameters for each flow temperature option entered in the PCDB[20].

Note: Heat pumps, when connected to hydronic emitters, can provide heat with a constant water flow rate or with a variable flow rate that is controlled to maintain a constant temperature difference through the emitter. Analysis showed that the SPF for a constant flow system was typically 5% lower than that for a variable system. Since constant flow systems are more common, this control option is used by default.

3.2.5 Weather Compensation

Equation (7) assumes weather compensation control applies (for space heating). If weather compensation control is absent or not specified (see 3.1.8), the equation is

[20] For a design flow temperature of 65°C, 55°C or 45°C it is not possible to utilise underfloor heating

disregarded. In this case the design flow temperature (for space heating) is applied constantly throughout the year, i.e. 65, 55, 45 or 35°C.

3.2.6 Hot water consumption assumptions

Operation of the heat pump in hot water mode (for service provisions (i) and (ii) only) is determined by considering the hot water vessel (cylinder or thermal store) at one uniform temperature. It is assumed that the vessel only demands heat when 1/3rd or more of the total heat that can be stored is depleted due to hot water draws-offs and vessel heat losses. A value of 1/3rd was chosen because cylinder thermostats are typically fitted approximately 1/3rd of the distance between the base and top of the cylinder. As cold water enters from the base the ascending cold mass contacts the thermostat when 1/3rd of hot water has been drawn off. During applications to the PCDB, heat pump manufacturers must declare the minimum acceptable hot water vessel volume to be connected to a given heat pump (see Appendix D). Due to longer recharge times, larger vessels may cause poor annual efficiency results overall. It is assumed that the vessel is located within the dwelling heated envelope.

The daily hot water energy requirement is determined with reference to English Housing Survey data, which use RdSAP calculation results (assuming inside/outside design day temperature difference of 24.2°C) to correlate against design space heat loss, see Figure 1.

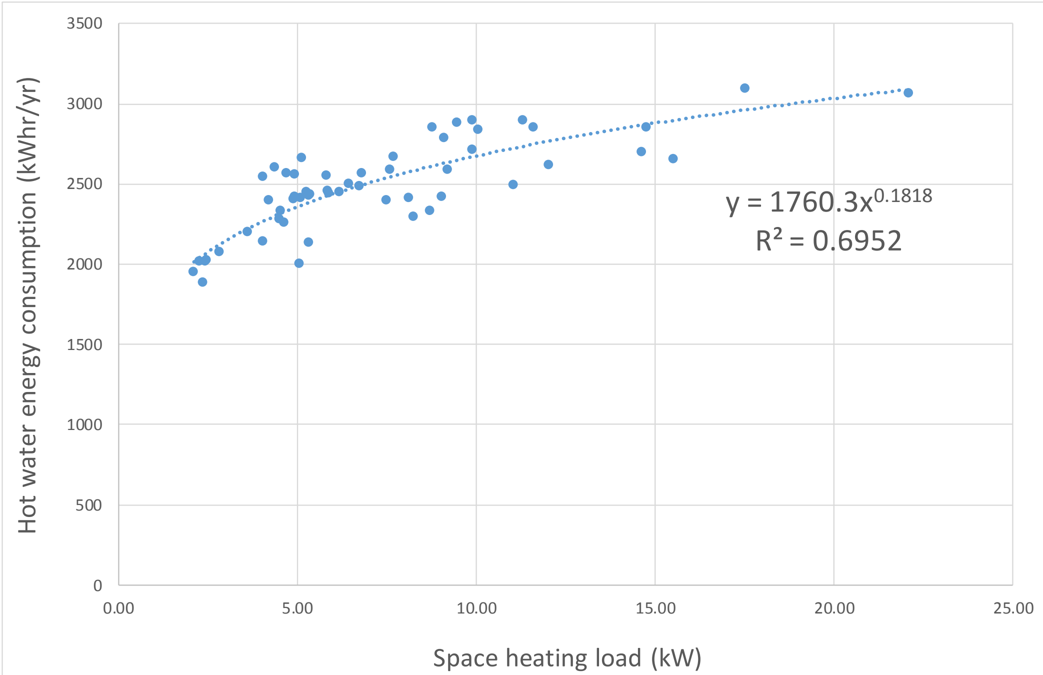

Figure 1 – Hot water energy consumption Vs space heating load

Heat pump space heating load (kW) is determined with respect to the heat pump capacity at design conditions and the Plant Size Ratio. It is used to estimate the hot water energy requirement.

The daily hot water tapping (or draw-off) times are based on EN16147 load profile "M", but with the energy content of each tapping proportionally scaled such that the total daily energy content matches the above assumption (Figure 1).

Table 2 displays the corrected hourly hot water schedule, where the energy requirement varies on a monthly basis with respect to cold water temperature, see Table 3. This hourly schedule is overlaid with the hourly space heating energy demand to determine hot water and space heating annual performance. The corrected hot water tapping energy ($Q_{w,tap}$) is calculated as:

$$Q_{W,tap} = Q_{Tap\_uncorrected} \times T_f \qquad (8)$$

The Temperature Factor (T_f) and uncorrected hot water tapping energy ($Q_{Tap\_uncorrected}$) is calculated as per equation:

$$T_f = \frac{(55 - T_{cold\_m})}{(55 - T_{av\_coldwat})} \quad \textbf{(9)}$$

Where:

T_{cold_m} = Monthly cold water temperature (°C)

$T_{av\_coldwat}$ = Annual average cold water temperature (°C) [12.8°C]

$$Q_{Tap\_uncorrected} = \frac{1760.3 \times \left({}^{\emptyset_{dgn}}/_{PSR} \right)^{0.1818}}{365} \times \left({}^{Q_{tap\_hour}}/_{5.845} \right) \quad \textbf{(10)}$$

Where:

Q_{tap_hour} = The sum of load profile M tappings within the calculation interval [hour] (kWh)

5.845 is the daily energy content of load profile "M" (kWh)

Scaled tapping profile M					
Month	Hour No	EN16147 Energy (Q_{tap_hour}) [kWh]	Temperature factor (T_f)	Uncorrected hot water tapping energy ($Q_{Tap\_uncorrected}$)	Corrected hot water tapping energy ($Q_{W,tap}$) [kWh]
	1	0.000	(55 - T_{cold_m}) / (55 - $T_{av\_coldwat}$)	1760.3 x ($\emptyset_{dgn}$ / PSR)$^{0.1818}$ / 365 * Q_{tap_hour} / 5.845	T_f x $Q_{Tapping\_DHW\_uncorrected}$
	2	0.000			
	3	0.000			
	4	0.000			
	5	0.000			
	6	0.000			
	7	0.000			
	8	1.610			
	9	0.420			
	10	0.210			
	11	0.105			
	12	0.210			
	13	0.315			
	14	0.000			
	15	0.105			
	16	0.105			
	17	0.105			
	18	0.000			
	19	0.315			
	20	0.105			
	21	0.735			
	22	1.505			
	23	0.000			

Table 2 – Daily hot water load profile

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Cold water inlet temperature (°C)	7.1	8.2	9.4	13.4	15.3	17.6	18.2	17.3	16.1	13.5	10.3	6.8

Table 3 - Monthly cold water temperatures (ºC)[21]

By default, the hot water vessel can only be heated during the specified water heating operating hours (see Section 3.1.5 for operating hours). Provided that sufficient evidence is provided, this assumption can be varied for alternative configurations of hot water vessel and control strategy.

3.2.7 Heat pump flow temperature for hot water service

For consistency with EN16147 test data, it must be possible to achieve a tapping (draw-off) temperature of 55°C (these occur at tapping 14 and 22 within the test). For the purposes of this calculation method it is therefore assumed that the hot water storage vessel is maintained at 55°C at all times[22].

A typical heat pump hot water vessel recharge cycle is displayed in Figure 2, whereby a cycle is initiated by tappings and/or vessel heat losses. It shows EN16147 test data from a test on a typical heat pump and hot water vessel and was conducted by the Building Research Establishment (BRE). From BRE's experience it is a very typical dataset, though it should be noted that the manufacturer opted to define the setpoint hot water vessel temperature as 52°C. From the recharge cycle test data it is possible to confirm:

- The average temperature difference (spread) at the condenser is 5°C, which is consistent with the EN15316-4-2:2017 standard assumption
- The average temperature difference between the bottom and top of vessel is 3°C
- The average of bottom and top vessel temperature readings is 46°C
- The average flow temperature is 52°C
- The maximum temperature difference between lower and upper vessel is 10°C
- The setpoint hot water temperature matches the average flow temperature (52°C)

[21] Energy Saving Trust - Solar thermal field trial data

[22] No explicit provision for Legionella growth prevention is included.

Therefore, given that the hot water storage vessel must be maintained at 55°C at all times, this calculation method assumes that the flow temperature during hot water service is a constant 55°C.

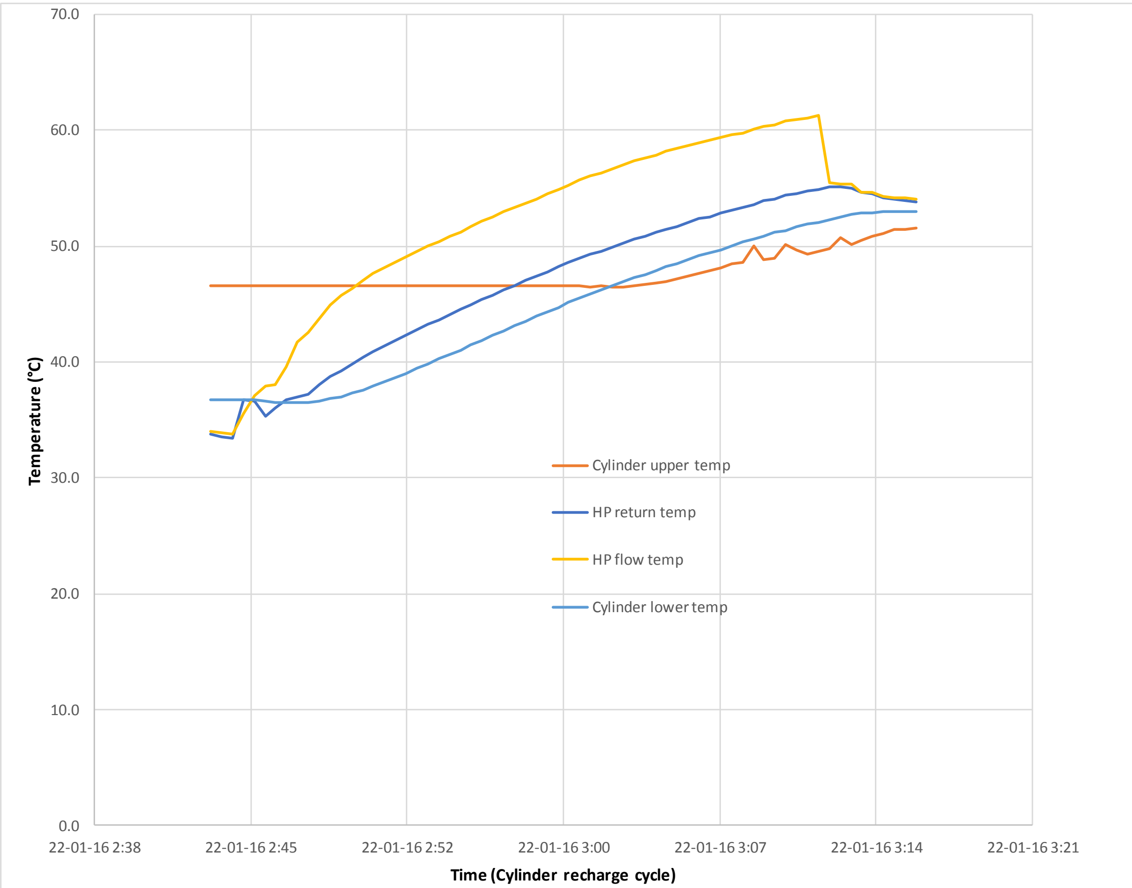

Figure 2 - Typical hot water vessel recharging cycle (from EN16147 tests)

3.2.8 Hot water vessel heat exchanger

The default assumption is an indirect hot water vessel with a typically sized heat exchanger coil[23]. As explained in Section 3.2.7, the average flow temperature during the recharging cycle matches the setpoint temperature.

[23] A minimum vessel heat exchanger area is specified by the heat pump manufacturer and recorded in the PCDB. It is not used for calculation purposes.

For cases where alternative heat exchangers are used, such as a Plate Heat Exchanger, a specific temperature difference between the heat pump flow temperature and setpoint vessel temperature can be implemented within the calculation. This will require demonstration of the average flow temperature that occurs during the recharging cycle of an EN16147 test (load profile M) in order to maintain a hot water vessel temperature of 55°C. Recharging is required due to hot water tappings and vessel heat losses. The recharge cycle during the test must not exceed one hour, unless satisfactory explanatory evidence is provided.

3.2.9 Hot water vessel heat loss and volume

Hot water vessel heat losses ($Q_{WS,ls,24}$) are declared by the heat pump manufacturer (in kWh/day), being either a fixed specification for a vessel sold or integrated to the heat pump, i.e. combination heat pump, or a worse-case vessel specification. The heat loss for a 45K temperature difference between the hot water vessel and its surroundings is tested in accordance with BS 1566 or EN 15332 or any equivalent standard and recorded in the PCDB. The standby power (P_{es}) tested according to EN16147 is not relevant[24]. It is always assumed that the vessel is installed within the dwelling heated envelope. The heat loss is used in the calculation of hot water heating SPF.

Declared heat losses are constant values and are therefore multiplied by a factor of 0.54[25], which is a factor in the SAP specification to reflect the daily temperature variation of the vessel contents. This ensures consistency with other water heating configurations in SAP. However, where a vessel is controlled to maintain a constant temperature at all times, this factor will not be applied - see Section 3.2.6.

If no vessel specification is declared, a default vessel specification of 150 litres and 1.9 kWh/day is applied in SAP calculations, with an in-use factor applied as defined in Section 3.1.3.

[24] Except for hot water only heat pumps

[25] 0.54 assumes water heating has separate time control - see SAP Table 2b

3.2.10 Auxiliary pump energy

The SPF calculation for all heat pump categories includes provision for circulation pump energy; this energy is not fully measured during EN14825 tests. The energy is added to the denominator of the SPF calculation and is taken as 15 Watts multiplied by the heat pump running time. This assumes a single pump is required; if more pumps are required and/or these pumps operate with an average power higher than 15 Watts, then the calculated SPF will likely be an overestimate.

The SPF calculation for Category 1): Ground (Indirect/Closed-loop: Brine to water) – includes brine circulation pump energy, which is additional to that measured during EN14825 tests. This energy is added to the denominator of the SPF calculation and is taken as either of the below options:

- 1.5% of thermal output capacity at EN14825 TOL condition (-10°C source and 35°C sink) or 100 Watts, whichever is the highest, multiplied by the heat pump running time
- Manufacturer declared rated brine circulation pump power multiplied by the heat pump running time. This pump must be included in the heat pump package.

The SPF calculation for Category 6): Water (Direct/Open-loop: Ground water to water) and Category 7): Water (Direct/Open-loop: Surface water to water) – includes pump energy, which is additional to that measured during EN14825 tests and may be significant. In order to submit a heat pump to the PCDB, the manufacturer must declare the maximum rated pump power, even if this is a maximum from a range of pump options. This power is multiplied by heat pump running time and added to the denominator of the SPF calculation.

3.2.11 COP correction for exhaust air heat pumps

For exhaust air heat pumps, Heat Pump Category 3) - 5), the Coefficient of Performance (COP) test results arising from EN14825 (via EN14511) or EN16147, are corrected to exclude the effect of system ductwork present during the test. For the purposes of this calculation method, the COP measurements entering the calculation method are unchanged. Accounting for the additional fan power required for connection to a domestic duct system within the COP is not necessary, it is separately accounted within the mechanical ventilation system parameters of the SAP calculation. It is assumed that all ductwork is installed within the dwelling heated envelope.

3.2.12 System boundary for SPF calculation

Figure 3 displays system boundaries for the determination of heat pump annual performance. The boundaries (and the image) were created during the SEPEMO-Build project (Seasonal performance factor and monitoring for heat pump systems in the building sector).

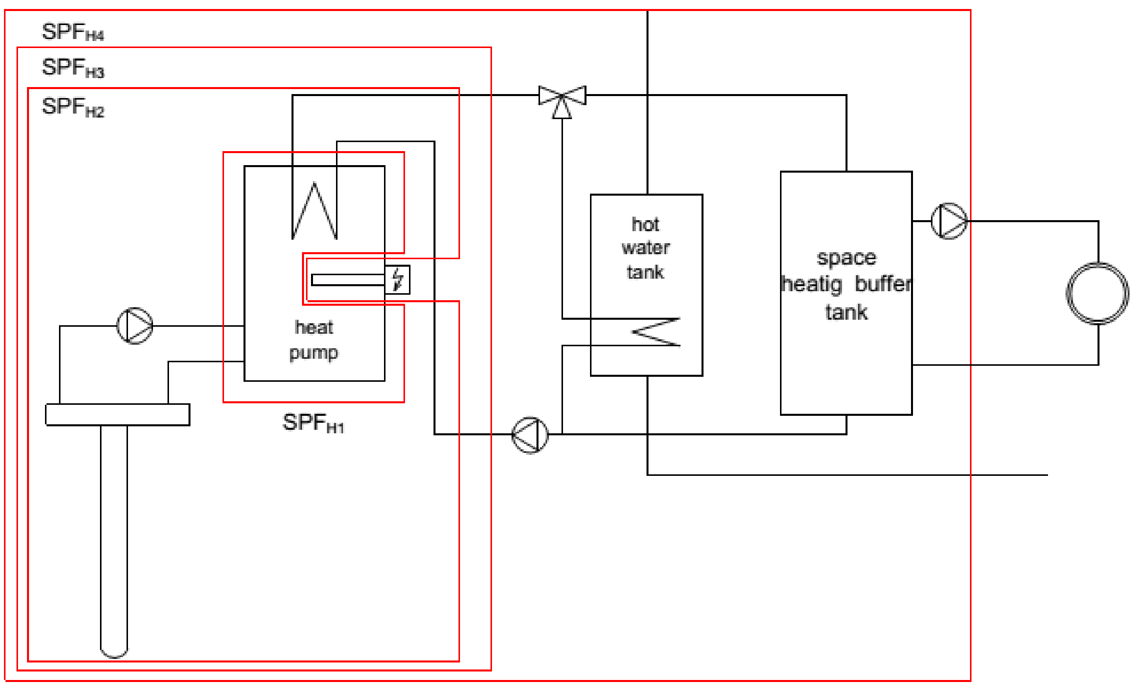

Figure 3 – SEPEMO system boundaries

The system boundaries used within this calculation method are identical to the SEPEMO SPF H4 definition, except that:

1) The SEPEMO SPF H4 definition merges both space and hot water heating SPF into a single value, this method must output two separate values for SAP calculations
2) The standard case for space heating SPF excludes a buffer vessel, which are not common for UK heat pump installations. The SAP calculation method ignores heat

pump buffer vessels, even if installed outside the heated envelope. It is assumed that the specification of a buffer vessel, in order to reduce on/off cycling and improve annual efficiency, will only occur if vessel heat losses do not negate this improvement (also see: Section 4.7).

The SEPEMO SPF H4 definition for hot water heating includes all heat energy supplied to the hot water vessel, including subsequent heat losses, within the numerator, as does the SAP heat pump calculation method. However, it should be noted that the SAP calculation itself considers these vessel heat losses as useful heat. The SAP calculation applies a monthly utilisation factor to the internal heat gains from hot water vessels.

The SAP space heating SPF calculation overlays a hot water energy demand schedule in priority to space heating energy demand. The hot water demand is scaled with heat pump rated capacity (at design condition) and month. This impacts the space heating SPF, specifically available running times. Such an arrangement is not explicitly specified within the SEPEMO SPF H4 definition, nor are any other control arrangements.

4. CALCULATION METHOD

4.1 Operating modes

There will be instances where combined operation of the heat pump for space heating and domestic hot water production is necessary during a calculation interval (one hour period), therefore four operation modes must be defined:

Modes:

1) Domestic hot water only operation - only domestic hot water system in operation (no space heating demand)

2) Combined heating and domestic hot water operation[26]

3) Space heating only operation - only space heating system in operation (hot water load satisfied or not present)

4) Storage operation – heat may be supplied to a hot water vessel/thermal store which can supply heating or hot water at a later time. The exact specification of this operating mode is not defined, since it relies on specific control strategies and will be utilised on a product specific basis as required

The calculation used in this standard assumes that both single and combined operation modes are tested according to standard EN14825 testing, so thermal capacity and COP characteristics are available[27].

[26] There is no European test standard for simultaneous operating heat pump systems. This method assumes that the flow temperature used for domestic hot water operation is a fixed temperature. If space heating is also required within a calculation interval, this is provided by the heat pump only when the hot water demand is satisfied. For heat pumps with "Variable" Capacity Control the calculation interval flow temperature for space heating is determined by the dwelling heat load, whilst it is fixed at a defined temperature for "Fixed" Capacity Control heat pumps

[27] This does not apply to hot water only heat pumps (service provision: iv), where only hot water production test data (EN16147) is required.

The calculation method, based on EN15316-4-2:2017, performs energy balance calculations for each calculation interval (1 hour). Heat pump Coefficient of Performance (COP) and capacity (kW) are determined for space and hot water heating with reference to EN14825 test data.

An overview of the calculation steps to be performed is listed below. This is undertaken for the heat pump at a range of PSR values.

Step 1: Determination of energy requirements for heating and hot water during the operational hours

Step 2: For each mode of operation, calculate the COP and thermal capacity for the calculation interval conditions using EN14825 test data (see EN15316-4-2:2017, Clause 6.7.3 and 6.7.2.7.2 if the compressor operates in on-off mode)[28].

Step 3: For each mode of operation, calculate the energy delivered by the heat pump system depending on climatic conditions and energy requirements

Step 4: Calculate the load ratio and running time of the heat pump in different operation modes

Step 5: Calculate energy for any back–up heating, if required

Step 6: Calculate auxiliary energy input at zero space and hot water load

Step 7 Calculate the annual SPF for space heating and water heating

[28] When EN14825 test conditions dictate a single source and sink temperature, the COP is determined using linear regression of the outside temperature (quadratic function) and the correction factor from Equation *D4* of EN15316-4-2:2017.

4.1.1 Combined domestic hot water and space heating (Mode 2)

For heat pumps undertaking both hot water and space heating modes within a calculation interval (see Section 4.1), the total heat pump running time is determined by the sum of the domestic hot water and space heating energy requirements, produced at the respective thermal capacity of the heat pump, with priority given to first satisfy hot water demand.

This operating mode requires the following additional calculation between steps 3 and 4:

Step A): Calculate separately the running time necessary to satisfy the domestic hot water energy requirement (priority 1) and space heating energy requirement (priority 2).

Step B): If there is insufficient time to satisfy the water heating energy requirement, set the water heating time (t_W) to the calculation interval (t_{ci}) and the space heating time (t_H) to zero. This means the heat pump is unable to operate in Mode 2 and remains in Mode 1 for the calculation interval.

Step C): Provided there is sufficient time to satisfy the water heating energy requirement within the calculation interval, and with time remaining, the heat pump will operate in Mode 2. If there is insufficient time to satisfy the water heating and entire space heating energy requirement, set the space heating time to the difference between calculation interval and the water heating time.

4.1.2 Storage for heating and domestic hot water

If space and water heating demand has been satisfied within a calculation interval (1 hour) or if satisfying storage heat demand has been assigned first priority, there is the potential for energy to be delivered by the heat pump to a storage system. This occurs when:

- Heat input to storage is authorized by the control system - this will depend on the exact control strategy, which will require specification by the manufacturer
- The minimum storage temperature from the heat pump system can be achieved
- The thermal storage is not fully charged

4.2 Hot water heating SPF for hot water (only) heat pumps

For hot water heat pumps (service provision: iv), EN16147 test data to load profile "M" must be available, otherwise an SPF value cannot be devised. The SPF (converted to efficiency format) is calculated from the below equation[29].

$$\eta_W = \frac{\left(5.845 + \left(Q_{WS,ls,24} \times 0.54\right)\right) \times 100}{\left(Q_{elec} - \left(P_{es} \times 24 \times 0.54\right) + \left(\frac{Q_{WS,ls,24}}{COP_{DHW}} \times 0.54\right)\right)} \quad \textbf{(\%)} \quad \textbf{(11)}$$

Where:

$Q_{WS,ls,24}$	is the daily hot water vessel heat loss (kWh/day) for a 45K temperature difference between the vessel and its surroundings. It is tested in accordance with BS1566 or EN15332 or any equivalent standard, though is not recorded in the PCDB. The vessel must be the same as that used during the EN16147 test[30]
Q_{elec}	is the electrical input energy (kWh) measured in the EN16147 test (defined as $\frac{Q_{ref}}{Q_{LP}} \times W_{EL-LP}$ in EN16147) over 24 hours
P_{es}	is the standby power (W) measured in the EN16147 test
COP_{DHW}	is the COP measured in the EN16147 test

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29 This includes the hot water vessel loss in the numerator explicitly, unlike the calculation within EN16147, where it is only included in the denominator. Note 1: Q_{elec} is corrected for auxiliary pump or fan power energy as per Section 3.2.11. Note 2: The SPF is converted to efficiency for PCDB entry.

30 The declared minimum hot water vessel volume entered in the PCDB can be up to 50 litres less than that tested and a minimum of 115 Litres, unless expressly advised by the manufacturer (with supporting evidence). The value of $Q_{WS,ls,24}$ for entry in the PCDB is declared by the manufacturer and may be up to 25% larger than the vessel used during the EN16147 test, it will not be used within the efficiency calculation (equation (11)). The value of 25% is derived from the typical difference between energy efficiency classes for hot water vessels within Ecodesign regulations.

No seasonal weather calculation is applied to hot water only heat pumps; EN16147 results are accepted as suitably representing annual performance, despite using a fixed source temperature. It is assumed that the vessel is located within the dwelling heated envelope.

If EN16147 test data to load profile "L" is also available, the SAP hot water SPF is determined using SAP 2012 equation N3.5 and Equation 11[31]. This interpolates or extrapolates an SPF (efficiency) using both "M" and "L" test measurements in accordance with the SAP daily hot water requirement of the dwelling being assessed[32].

4.3 Hot water heating SPF for other heat pump types

For all other heat pump types (service provision: i, ii, iii), including combination heat pumps, where EN16147 test data may be available, this data will not be used.

Hot water heating SPF is determined in accordance with the space heating method[33], see following sections, using a monthly flow temperature requirement, see Section 3.2.7. However, in order to determine this SPF, which also affects space heating SPF, the hot water heating running times are required.

For calculation interval t+1, the energy content of the hot water vessel ($Q_{WS,t+1}$) is calculated from:

$$Q_{WS,t+1} = Q_{WS,t} - Q_{W,tap} - Q_{WS,ls} \quad \textbf{(kWh)} \qquad \textbf{(12)}$$

[31] Though 5.845 kWh/day is replaced with 11.655 kWh/day, which is the load profile “L” energy requirement.

[32] Solar assisted hot water only heat pumps could, in principle, have their hot water SPF determined in accordance with the method in Section 4.3, if EN14825 test data were available. This would require development of certain test specifications and the correction of source temperature at hourly calculation intervals with respect to insolation.

[33] NOTE: Since only one hot water heating efficiency can be held in the SAP 2009 and 2012 PCDB, the hot water heating SPF is based on the average of all results for the standard PSR range, see Section 3.1.6. For SAP 2016, a hot water heating SPF is held for each PSR.

$Q_{WS,t}$ is the energy in the store at previous calculation interval '*t*'

$Q_{w,tap}$ is the energy drawn-off from the vessel during the calculation interval '*t*'.

$Q_{WS,ls}$ is the average vessel heat loss during the calculation interval 't', see Section 3.2.9.

The hot water vessel can only be supplied with heat when a demand is present during heat pump operating hours. To determine if a heat demand is present during a calculation interval the vessel energy content must be less than two thirds of its maximum value, that is:

IF: $Q_{WS,t+1} \leq 2 \times Q_{WS,\max} / 3$ **(kWh)** **(13)**

THEN - A hot water demand exists. The hot water energy requirement ($Q_{W,gen,out}$) is defined as:

$(Q_{W,gen,out}) = Q_{WS,max} - Q_{WS,t+1}$

Upon completion of the calculation interval, the hot water energy requirement is satisfied, even if additional back-up energy is required. Therefore:

$$Q_{WS,t+1} = Q_{WS,\max}$$

Where:

$$Q_{WS,\max} = V_{WS,\max} \times 45 \times 4.18 / 3600$$

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

45K is assumed average temperature rise and 3600 converts units to kWh

$V_{WS,\max}$ is the storage volume in litres.

If the hot water energy requirement can be satisfied within the calculation interval, and with surplus time, the calculation interval will operate as Mode 2 if a space heating energy requirement exists, see Section 4.1.1.

Outside the hot water operating hours or when there is no demand for domestic hot water the calculation proceeds to the next calculation interval starting at equation (9).

If no hot water energy requirement exists within the calculation interval, the calculation interval will operate as Mode 3 if a space heating energy requirement exists, see Section 4.1.1.

4.3.1 Alternative calculation for transcritical heat pumps

Where a heat pump utilises a transcritical cycle, via a refrigerant such as CO_2, this calculation method is unlikely to be accurate during hot water mode. This is because the sink temperature spread during the recharging cycle will be significantly different to the standard 5°C assumption - see Section 3.2.7.

Provided that the following requirements are satisfied, an alternative hot water SPF calculation can be applied:

- Heat pump package is defined as a combination heat pump as per Ecodesign regulations (No. 811/2013).
- Heat pump package implements a transcritical cycle.
- Heat pump package demonstrates a sink temperature difference in hot water mode that is substantially different to space heating mode.
- Hot water heating mode of heat pump package operates independently of space heating mode and does not affect it.
- Hot water heating mode capacity is equal or higher than space heating capacity for the same source temperature.

The required hot water heating test data for such a heat pump is:

- Three complete EN16147 test reports for load profile M at source temperatures: 20°C, 7°C, and -7°C [It is noted that -7°C is not a standard condition within EN16147].

- EN16147 test reports must include the flow temperature (°C) and capacity (kW) during a recharging cycle at a minimum 10 second resolution. The cycle must not exceed one hour, unless supporting evidence is provided.
- EN16147 test reports must include all auxiliary pumps necessary for operation.
- Confirmation of the proportion of hot water vessel volume, whether indirect or direct, that must be drawn-off before a heat pump recharging cycle is requested.
    - If this is user variable, the minimum must be specified. This will be used within the calculation method and may differ from the 1/3 assumption used within the standard method - see Section 4.3.
- Manufacturer must declare if hot water vessel temperature is maintained continuously or only during timed periods. The standard assumption is that recharging only occurs during SAP heating hours.

The alternative hot water heating SPF calculation will substitute COP and capacity values arising from EN14825 data (see Section 4.3) for each calculation interval (hour) and follows the process:

1) Modify EN16147 COP results (x3) to include hot water vessel heat loss values, as per Section 4.2, Equation (11). Note: This equation is ordinarily used for converting COP results to annual efficiency (%), it should therefore be divided by 100. If vessel is continuously heated, then "0.54" factor should be omitted from Equation (11).
2) For each calculation interval, overwrite the hot water heating COP with a COP obtained via linear interpolation using the interval source temperature and values obtained from 1).
3) Derive the hot water heating capacity during the recharging cycle for each EN16147 test data set.
4) For each calculation interval, overwrite the hot water heating capacity with a capacity obtained via linear interpolation using the interval source temperature and capacity values obtained from 3).
5) If different from standard assumptions (i.e. 1/3 reduction in hot water vessel energy content causes a recharging cycle to commence, see Section 4.3), amend as appropriate.
6) Run the calculation method

4.4 Heat capacity under operating conditions

These calculations are based on the temperature at the evaporator and the temperature at the condenser and are calculated separately for each operating mode.

The Temperature Operation Limit (TOL) is defined in EN14825 as *“the lowest outdoor temperature at which the unit can still deliver heating capacity and is declared by the manufacturer. Below this temperature the heat pump will not be able to deliver any heating capacity.”* The weather data used within this calculation method does not feature a source temperature at or below the “TOL” test temperature (which is -7°C to -10°C). Therefore, test data at the TOL test condition is not used (Test condition “A” at -7°C is sufficient).

If the thermal capacity of the heat pump is higher than the energy requirement then:

- Fixed Capacity Control heat pumps cycle on and off in proportion to the energy demand and thermal capacity.
- Variable Capacity Control heat pumps (Invertor type) adapt the capacity to the heat load. However, below a certain capacity limit (determined with $LR_{cont;min}$, see Section 4.5.9) the heat pump will cycle on/off between the minimum rate and zero rate.

The thermal capacity at the operating conditions during the calculation interval are derived from EN14825 test data using the following equations (33) and (34) from EN15316-4-2:2017.

Note: formulae *(34), (36) and (37)* are presented in EN15316-4-2:2017 in a simplified form without accounting for the influence of the temperature spread at the evaporator and condenser of the heat pump. The exact effect of the spread in temperature is complex but D.4 of EN15316-4-2:2017 provides an approximation that may be used and is the basis of this calculation method.

For fixed capacity control heat pumps the heat output at operating conditions is:

$$\Phi_{\vartheta in;\vartheta out;X(t)} = \Phi_{cld;ref} + (\Phi_{D;ref} - \Phi_{\text{cld};ref}) \times \frac{(\Delta\vartheta_{in;out;\text{cld}} - \Delta\vartheta_{in;out;X}(t))}{(\Delta\vartheta_{in;out;\text{cld}} - \Delta\vartheta_{in;out;D})} \quad \text{(kW)} \qquad (33)$$

Φ is the heat capacity; the subscript '$\vartheta in;\vartheta out;X(t)$' refers to the calculation interval, the subscript 'D' refers to EN14825 test condition D and the subscript "cld" refers to test condition A[34].

$\Delta\vartheta_{in;out;}$ is the temperature difference between the source and sink temperature for the EN14825 test condition A and test point D.

X (subscript) refers to the operating conditions for the service provided (e.g. heating, hot water or storage) within the calculation interval

For variable capacity control heat pumps the heat output at operating conditions is:

$$\Phi_{\vartheta in;\vartheta out;X}(t) = \Phi_{cld} \times \left[\frac{(\vartheta_{gen;out;\text{cld}} + 273{,}15)/(\vartheta_{gen;in;\text{cld}} + 273{,}15)}{(\vartheta_{gen;out;X(t)} + 273{,}15)/(\vartheta_{gen;in;X(t)} + 273{,}15)} \right]^{n\_exer} \quad \text{(kW)} \qquad (34)^{35}$$

Where: *n_exer* = 3 (Exergy Exposure Factor – Table 9, EN15316-4-2:2017)

In the case of all Heat Pump categories, other than 2) (air to water), when these are tested with a fixed outlet water (flow) temperature during EN14825 tests, the test conditions A - D are consequentially undertaken with the same source and sink temperatures. In such cases the mean capacity is used.

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[34] Note: EN14825 defines the Bivalent Temperature as the *"lowest outdoor temperature point at which the unit is declared to have a capacity able to meet 100 % of the heating load. Below this temperature, the unit may still deliver capacity, but additional back up heating is necessary to fulfil the entire heating load".* For the purposes of EN15316-4-2:2017 and this calculation method, EN14825 COP test data (only) arising at the bivalent test point (F) is used for interpolation purposes only (as with test points A-D), since the bivalent temperature is effectively determined for each calculation interval. EN15316-4-2:2017 defines the Bivalent Temperature *"as the lowest temperature at which the heat pump capacity and building heat load are equal."*

[35] Note: EN15316-4-2:2017 refers to output at the bivalent point, which is defined in accordance with that standard and not the EN14825 definition. "biv" is replaced with "cld" to avoid confusion, it is always taken as EN14825 test condition A (-7°C).

4.5 COP under operating conditions

The COP under operating conditions is calculated from the interpolation of the exergetic efficiency using a modified load factor.

4.5.1 Carnot COP at operating conditions

$$COP_{gen;exer} = \frac{\vartheta_{gen;out}(t) + 273{,}15}{\vartheta_{gen;out}(t) - \vartheta_{gen;in}(t)} \quad \text{(-)} \qquad (36)$$

$COP_{gen;exer}\left(J_{gen;in}; J_{gen;out}\right)$ is the Carnot COP for the operating conditions

$J_{gen;in}$ is the source temperature at the heat pump (°C)

$J_{gen;out}$ is the sink (flow) temperature at the heat pump (°C)

4.5.2 Exergetic load factor at operating conditions

$$LR_{exer;X} = \frac{COP_{exer;X}}{COP_{exer;\mathrm{cld}}} \times \left[\frac{(\vartheta_{out;\mathrm{cld}} + 273{,}15)/(\vartheta_{in;cld} + 273{,}15)}{(\vartheta_{out;X} + 273{,}15)/(\vartheta_{in;X} + 273{,}15)} \right]^{n\_exer} \quad \text{(-)} \qquad (37)$$

4.5.3 Exergetic load factor, Carnot COP and exergetic efficiency for EN14825 conditions

$$LR_{exer;R} = \frac{COP_{exer;\mathrm{R}}}{COP_{exer;\mathrm{cld}}} \times \left[\frac{(\vartheta_{out;\mathrm{cld}} + 273{,}15)/(\vartheta_{in;\mathrm{cld}} + 273{,}15)}{(\vartheta_{out;R} + 273{,}15)/(\vartheta_{in;R} + 273{,}15)} \right]^{n\_exer} \quad \text{(-)}$$

$$COP_{gen;exer;R} = \frac{\vartheta_{gen;out;\mathrm{R}} + 273{,}15}{\vartheta_{gen;out;\mathrm{R}} - \vartheta_{gen;in;R}}$$

$$f_{LR;exer;R} = COP_{ref;R} / COP_{exer;R} \quad \text{(-)} \qquad \text{(Table D3)}$$

Note: *'COP_{ref}'* refers to EN14825 results; *'R'* refers to each test condition: A – D and F. The subscript *'cld'* refers to the COP or temperature at the coldest source temperature for which there is a measurement.

A minimum temperature difference of 6K between the source and sink temperature is applied to prevent very high Carnot COPs entering the calculation. This only arises when the temperature difference and heating load is small, and is unlikely to affect the calculated SPF.

4.5.4 Exergetic efficiency at operating conditions

This is calculated by the linear interpolation of the nearest test Exergetic efficiencies (points XX and YY) to that of the operating temperatures using the nearest exergetic load factors (XX and YY) as shown below.

$$f_{LR;exer;X}(t) = f_{LR;exer;XX} - \left(f_{LR;exer;XX} - f_{LR;exer;YY}\right) \times \left[\frac{LR_{exer;XX} - LR_{exer(t)}}{LR_{exer;XX} - LR_{exer;YY}}\right] \text{(-)} \quad (38)$$

4.5.5 COP at operating conditions

The COP at the calculation interval operating conditions is calculated from:

$$COP_{gen,\vartheta in,\vartheta out}(t) = f_{LR;exer;X(t)} \times COP_{gen,exer}(t) \qquad \text{(-)} \qquad (39)$$

The minimum COP is set at 1, since values less than this are likely to be extrapolation errors[36].

4.5.6 COP when test data measured at single source temperature and fixed outlet (flow) temperature

Category 1), 3) - 7) heat pumps are tested with a single source temperature during EN14825 tests (Measurements A to D and F). If tests are undertaken with fixed outlet (flow) temperature control, the calculations steps defined in Section 4.5.1 to 4.5.5, which are taken from EN15316-4-2:2017, are not possible. An alternative approach is defined below:

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[36] The effective COP for a complete time interval may be less than 1 due to on/off operation at low heat loads.

1) Calculate the best fit quadratic equation of COP at test points A - D and F against the outside temperature (T_o), i.e. $COP_{gen;To} = (a \times T_o^2) + (b \times T_o) + c$, where a, b and c are the best fit linear regression coefficients.
2) Use quadratic regression equation to calculate the COP at the outside temperature for calculation interval.
3) Correct the COP to account for the operating temperatures using:

$$COP_{gen}(\vartheta_{in};\vartheta_{out}) = COP_{gen;T_o} \frac{\left(\vartheta_{gen;out,X} + 273{,}15\right) \times \left(\vartheta_{gen;out;ref} - \vartheta_{gen;in;ref}\right)}{\left(\vartheta_{gen;out;ref} + 273{,}15\right) \times \left(\vartheta_{gen;out,X} - \vartheta_{gen;in,X}\right)} \quad (-) \quad (D4)$$

NOTE: $\vartheta_{gen;out,X} - \vartheta_{gen;in,X}$ is subject to $\Delta\theta_{min}$, which is a global minimum temperature difference applied throughout the calculation method – default 5K. The subscript 'ref' refers to EN14825 test conditions A to F, but in this case the sink and source temperatures don't vary between conditions.

4.5.7 Temperature spread adjustment

From Equation (7), the temperature spread (difference) across the heat emitters (condenser/sink) can be determined from:

$$\Delta\vartheta_{gen,out}(t) = \frac{24 \times f \times (T_b - T_o) \times \Delta T_{E,d}}{h \times \Delta T_{d,d}} \quad \textbf{(K)} \quad \textbf{(14)}$$

(See Section 3.2.4 for symbol definitions)

The precise evaluation of the thermodynamic process involves the temperature spread at the evaporator and condenser which depends on the refrigerant temperature and other properties which are too complex to include in the formulae *(34), (36)* and *(37)* in EN15316-4-2:2017. Instead, EN15316-4-2:2017 gives a correction factor *(D8)*. This correction factor is applied to the COP and is only applicable when the temperature spread at the condenser during the calculation interval differs from that at the test condition during space heating operation. The SPF during space heating mode[37] is corrected as follows:

$$COP_{gen;\vartheta in;\vartheta out;\Delta\vartheta}(t) = f_{COP;\vartheta in;\vartheta out;\Delta\vartheta} \times COP_{gen;\vartheta in;\vartheta out}(t) \quad \text{(D8)}^{38}$$

Where:

$$f_{HP;COP;\vartheta in;\vartheta out;\Delta\vartheta} = \left[1 - \frac{0.5\left(\Delta\vartheta_{gen;out;ref} - \Delta\vartheta_{gen;out}(t)\right)}{\vartheta_{gen;out}(t) + 273,15 - 0.5\Delta\vartheta_{gen;out;ref} + \Delta\vartheta_{HP;gen;cond;int} - \left(\vartheta_{gen;in}(t) + 273,15 - \Delta\vartheta_{HP;gen;evap;int}(t)\right)}\right]$$

$f_{HP;COP;\vartheta in;\vartheta out;\Delta\vartheta}$ is a factor applied to the COP for different temperature spreads at the heat pump sink and source (-)

$COP_{gen;\vartheta in;\vartheta out;\Delta\vartheta}(t)$ is the COP corrected for different temperature spreads between testing and operation

$COP_{gen;\vartheta in;\vartheta out}(t)$ is the calculated COP assuming the operating temperature spread is the same between testing and operation.

$\Delta\vartheta_{gen;out;ref}$ is the temperature spread on the condenser under standard test conditions

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[37] No correction is necessary for hot water heating or storage mode, since EN15316-4-2:2017 assumes operating temperature spread is the same as the test conditions during these modes of operation.

[38] The original equation in EN15316-4-2:2017 involves terms $\Delta\vartheta_{ref}$ and $\Delta\vartheta_{gen;out;ref}$ with the latter undefined but evidently it is the same as $\Delta\vartheta_{ref}$. So $\Delta\vartheta_{ref}$ in the denominator has been replaced by $\Delta\vartheta_{gen;out;ref}$.

$\Delta\vartheta_{gen;out}(t)$ is the temperature spread on the condenser in operation due to the design of the heat emitter system

$\vartheta_{gen;out}(t)$ is the temperature at the outlet of the condenser (sink temperature)

$\Delta\vartheta_{HP;gen;cond;\text{int}}(t)$ is the average temperature difference between heat transfer medium and refrigerant in condenser (5K see EN15316-4-2:2017 Table D1).

$\Delta\vartheta_{HP;gen;\text{evap};\text{int}}(t)$ is the average temperature difference between heat transfer medium and refrigerant in evaporator (5K for air and exhaust air heat pumps and 10K for water and ground source heat pumps see EN15316-4-2:2017 Table D1).

$\vartheta_{gen;in}(t)$ is the temperature at the inlet of the evaporator (source temperature)

4.5.8 Driving energy during continuous operation

This mode only occurs for variable capacity heat pumps. Calculate the operating time of each service from the energy requirement ($Q_{\vartheta in;\vartheta out;X;out}$) and the heat capacity ($\Phi_{\vartheta in;\vartheta out;X}$)[39] of the heat pump using the following:

$$LR = \sum_X \frac{Q_{\vartheta in;\vartheta out;X;out}}{\Phi_{\vartheta in;\vartheta out;X} \times t_{ci}} \text{ (-) and } t_X = \frac{Q_{\vartheta in;\vartheta out;X;out}}{\Phi_{\vartheta in;\vartheta out;X}} \text{ (h)} \qquad (35)$$

Where:

- For the first service required (hot water) the operating time is subject to the calculation interval duration (1 hour)

[39] Assuming maximum capacity at a given source temperature; ignoring that heat pump control may modulate capacity in practice.

- For the second service required (space heating) the operating time is subject to the calculation interval duration (1 hour) minus operating time of first service
- For the third service required (storage) the operating time is subject to the calculation interval duration (1 hour) minus operating time of the first and second service

The compressor driving energy input for continuous operation during each service is derived from the values for COP, operating time and thermal capacity as:

$$E_{gen;\vartheta in;\vartheta out,\Delta\theta,X}(t)=\frac{\Phi_{\vartheta in;\vartheta out;X}(t)\times t_X}{COP_{gen;\vartheta genin;\vartheta genout}(t)} \quad \text{(kWh)} \qquad (40)$$

Where t_x is the operating time during the calculation interval for each service; a separate value is calculated for each service provision.

4.5.9 Calculating minimum modulation rate

Variable capacity control heat pumps (Invertor type) can adapt their capacity to the heat load. However, below a certain capacity limit, they operate on/off. This limit, known as the minimum modulation rate ($LR_{cont;min,X}(t)$) is a flow temperature dependent variable determined for each time-step by linear interpolation between two fixed minimum rates that are declared by the heat pump manufacturer. One of these rates is determined at a flow temperature of 55°C ($LR_{cont;min,55}$), whilst the other is determined at a flow temperature of 35°C ($LR_{cont;min,35}$). The flow temperature will vary for each heating service within a calculation interval, hence the subscript X reflects the service number.

For flow temperatures higher than 55°C, the minimum modulation rate at 55°C will be used. For flow temperatures below 35°C, the minimum modulation rate at 35°C will be used.

The fixed minimum modulation rate $LR_{cont;min,55}$ is determined by:

1) Obtaining the heat pump capacity at EN14825 test condition C (source temperature: 7/6°C) using a 'medium temperature application' (55°C)

2) Obtaining the EN14511 standard rating condition capacity at 55°C (source temperature: 7/6°C)
3) Dividing 1) by 2)

The fixed minimum modulation rate $LR_{cont;min,35}$ is determined by:

1) Obtaining the heat pump capacity at EN14825 test condition C (source temperature: 7/6°C) using a 'low temperature application' (35°C)
2) Obtaining the EN14511 standard rating condition capacity at 35°C (source temperature: 7/6°C)
3) Dividing 1) by 2)

4.5.10 Driving energy during on/off operation

This mode occurs for:

- Fixed capacity control heat pumps
- Variable capacity control heat pumps when the load ratio at operating conditions is lower than the lowest possible load ratio applicable to the compressor

The calculation of driving energy during on/off operation is undertaken separately for each service (X) provided.

1) Calculate the power of the compressor at the lowest possible continuous load

$$P_{gen,LR;comp;min,X}(t) = P_{gen,LR100,X}(t) \times LR_{cont;min,X}(t) \quad \text{(kW)} \qquad (26)$$

$LR_{cont;min,X}(t)$ is the minimum continuous load ratio at the operating flow temperature for the delivered service

$P_{gen,LR100,X}(t)$ is the power of the heat pump at maximum output (100%) under the temperature conditions of calculation interval *'t'.*

2) The power used due to non-reversibility of the heat pump (inertia) is $P_{gen;comp;ONOFF;LR}(t)$. This is equal to 0 when the load ratio (LR) is greater than or equal to $LR_{;cont;min,X}$(t). (LR is calculated as per Equation (35) in Section 4.5.8). For lower load ratios, it is equal to:

$$P_{gen;comp;ONOFF;LR}(t) = P_{gen;LR;comp;min,X}(t) \times \frac{\tau_{eq} \times LR \times (1 - LR)}{\tau_{out,em,type}} \quad \text{(kW)} \qquad (28)$$

τ_{eq} is a characteristic parameter of the heat pump, due to the inertia of the On/Off transient (default 140 Seconds).

$\tau_{out,em,type}$ represents the operating time to reach the required conditions of the emitter distribution system. This value depends on the category of emitters for heating and temperature of the domestic hot water. Default time characteristic values are defined in Table 4 (reproduced from EN15316-4-2:2017 Table 13). For the purposes of this calculation method the non-greyed out values are used, irrespective of actual emitter type.

Inertia	**Heavy embedded emitters**	**Light embedded systems**	**Low**	**Very low**	**Domestic hot water & storage**
Type of emitters	Wet system with coverage higher than 10 min (based on EN1264)	Wet system with coverage lower or equal to 10 min (based on EN1264)	Air handling unit Heating and cooling ceiling (low inertia) Fan coil unit	Air systems	–
$\tau_{out,em,type}$ [s]	1920	1370	360	120	1560

Table 4 - Time characteristics for energy delivery

3) Consumption of the compressor during the off-part of the on/off cycle ($E_{X,gen,aux}$)

This part of the calculation involves the degradation coefficient (Cdh) from EN14825 tests. A value is quoted for each test condition (A - D and F) and for each operating mode.

For variable capacity control heat pumps or fixed capacity control with variable output temperature, obtain the two values of exergetic load factor calculated from the test data either side of the exergetic load factor for the calculation interval operating conditions. Additionally, obtain the two corresponding values of the degradation coefficients. By linear interpolation calculate the degradation coefficient for the operating condition as follows:

$$Cdh(t) = Cdh_{XX} - (Cdh_{XX} - Cdh_{YY}) \times \left[\frac{LR_{exer;XX} - LR_{exer(t)}}{LR_{exer;XX} - LR_{exer;YY}} \right] \quad \text{(-)} \qquad (15)$$

In the case of all Heat Pump categories, other than 2) (air to water), when these are tested with a fixed outlet water (flow) temperature during EN14825 tests, the test conditions A - D are consequentially undertaken with the same source and sink temperatures. In such cases the mean degradation coefficient (Cdh) is used.

If the calculated value of Cdh(*t*) is lower than 0.9 then restrict to 0.9, and if higher than 1 then restrict to 1. Transfer the result to equation (16) for each calculation interval.

$$E_{X,gen,aux} = (1 - Cdh(t)) \times P_{gen;LR100,X(t)} \times t_{off,x} \quad \text{(kWh)} \qquad (16)$$

For the first service (hot water heating) calculation, if during the calculation interval only this service is provided for time period "t_1" (i.e. $t_2 = 0$ and t_3=0), then set $t_{off,1} = t_{ci} - (LR_1/LR_{cont,min,1} \times t_{ci})$, subject to a minimum of zero, and calculate $E_{1,gen,aux}$. If either a second or third service is also provided during the calculation interval $E_{1,gen,aux}$ = 0.

For the second service (space heating) calculation, if during the calculation interval the second service is provided for time period "t_2", and not the third service (i.e. $t_2 > 0$ and $t_3 = 0$), then set $t_{off,2} = t_{ci} - t_1 - (LR_2/LR_{cont,min,2} \times t_{ci})$, subject to a minimum of zero, and calculate $E_{2,gen,aux}$. If the third service is provided $E_{2,gen,aux}$= 0.

For the third service (storage) calculation, if during the calculation interval the third service is provided for time period "t_3", set $t_{off,3} = t_{ci} - t_1 - t_2 - (LR_3/LR_{cont,min,3} \times t_{ci})$, subject to a minimum of zero, and calculate $E_{3,gen,aux}$. If the third service is not provided $E_{3,gen,aux}$= 0.

4) Corrected heat pump driving energy and COP [*(29)* with (12) added in]:

$$E_{X;\text{gen,in}}(t) = (f_{aux} \times (1 + E_{gen;\vartheta in;\vartheta out}(t)) + P_{\text{gen,comp,ONOF,LR}}) \times t_X + E_{X,gen,aux} \quad \textbf{(kWh)} \qquad (17)$$

Where f_{aux} is fraction of auxiliary energy that is not implicitly included in the COP measurements when operating continuously. The default is zero for electric heat pumps[40].

$$\mathrm{COP}_{X;gen;\mathrm{LR}}(t) = \frac{Q_{\mathrm{X;gen;out}}(t)}{E_{X;\mathrm{gen;in}}(t)} \qquad (-) \qquad \textit{(30)}$$

4.6 Back-up energy

EN15316-4-2:2017 distinguishes between "back-up energy" and "additional energy". Back-up energy refers to energy supplied by a back-up heater within the heat pump package. The heat capacity of the heater is an input specification. Additional energy refers to extra energy required because the heat pump and its back-up heater cannot meet the required demand.

For SAP calculation purposes no such distinction is required and "back-up" in this method applies to the total of both. This back-up energy is assumed to be direct-electric.

Back-up energy is required when:

1) the source temperature is below the declared temperature operating limit of the heat pump (TOL)
2) the required flow temperature is above the maximum operating temperature limit of the heat pump
3) energy provided by the heat pump is insufficient to meet the total demand for all the required services

Back-up energy is the difference between the total for required services and the heat energy produced by the heat pump.

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[40] It will be non-zero for non-electric heat pumps.

$$Q_{gen,bu,out} = Q_{H,gen,dis,out} + Q_{W,gen,dis,out} - (\phi_H \times t_H) - (\phi_W \times t_W) - (\phi_S \times t_S) \qquad \text{(kWh)} \qquad \textbf{(18)}$$

If the result is negative, then no back-up energy is required.

Total back-up energy is assigned to hot water heating first, then if further energy is required to space heating and finally to any heat storage service.

4.7 Auxiliary electrical consumption

The auxiliary electrical consumption of a heat pump when there is a demand for a heating service is already incorporated into the electrical input test measurement and hence the COP (see Section 4.5.8). This includes the effect of cycling on and off when there is a small heat demand (see Section 4.5.9).

NOTE: This method assumes that where a heat load exists, causing operation of the heat pump, the heat emitter system is capable of emitting that heat. In certain circumstances "short cycling" may occur, where heat pump run times are shortened to sub-optimal small time periods, reducing annual performance and typically caused by poor control arrangements. This phenomenon is not accounted for within the method and may result in poorer annual performance than that predicted by the method.

4.7.1 Auxiliary electrical consumption at zero load

This section is concerned with the auxiliary electrical consumption when the demand for a heating service is zero. This occurs when:

1) Heat demand satisfied
2) Outside the operating hours

EN14825 test data contains information about the power consumption during off mode (P_{off}), standby mode (P_{SB}) and crankcase heater mode (P_{CK})[41]. These are utilised in

[41] Thermostat-off mode power (P_{TO}) is not used within the calculation method.

conjunction with the operating hours at zero heat load and non-operation hours (e.g. overnight) to calculate the energy consumption.

EN14825 test data has two crankcase heater test scenarios:

Scenario 1: *"If the crankcase heater is on during standby measurements, then the power consumption due to the crankcase heater mode shall be considered equal to the standby power consumption."* Here the crankcase heater is included in the standby consumption measurement and the power consumption of both modes are reported as equal in the test report. In such cases, the calculation should set P_{CK} to zero to prevent double-counting.

Scenario 2: Separate test of crankcase heater required. *"If the crankcase heater is not operating during standby measurement then a test shall be performed as follows: After the "B" temperature conditions test in heating mode is finished, the unit is stopped with the control device, and the energy consumption of the unit shall be measured for 8 h. Average of 8-hour power input shall be calculated. The standby power consumption is deducted from this measured energy consumption to determine the crankcase heater operation consumption."* Here the crankcase heater consumption measurement excludes the standby consumption measurement. These different values are both reported in the test report.

For the avoidance of doubt, the crankcase heater consumption in this method assumes it excludes standby consumption. If this is not the case the crankcase heater and standby consumption measurements must be adjusted accordingly.

When the calculation interval coincides with space heating operational hours:

$$E_{\mathrm{gen;in;LR0}}(t) = (P_{SB} + P_{CK}) \times (t_{ci} - t_H - t_W - t_S) \quad \text{(kWh)} \quad \textbf{(19)}$$

Where t_{ci}, t_H, t_W, and t_S are respectively, the calculation interval, the space heating operating time, water heating operating time and storage operating time.

When the calculation interval is outside the heating season (i.e. June to September) and within water heating operational hours:

$$E_{\mathrm{gen;in;LR0}}(t) = P_{SB} \times (t_{\mathrm{ci}} - t_H - t_W - t_S) \qquad \text{(kWh)} \qquad \textbf{(20)}$$

When the calculation interval is outside the space heating and water heating operation hours:

$$E_{\mathrm{gen;in;LR0}}(t) = P_{off} \times (t_{ci}) \qquad \text{(kWh)} \qquad \textbf{(21)}$$

4.7.2 Additional auxiliary electrical consumption during running

This section is concerned with auxiliary electrical consumption not measured during standard tests. The electrical energy assumptions are detailed in Section 3.2.10. The sum of auxiliary pump energy is defined as: $E_{gen;in;aux}$.

The electrical energy consumed by auxiliary pumps is determined by the running time of each service. When the heat pump operates in on/off mode the running time is the time needed to operate at minimum continuous load; this is full load for constant output systems.

When operating at continuous, but part load conditions, the running time is as follows:

a) When only a single service is provided in the calculation interval then the running time is set to calculation interval.
b) When two or more services are provided in the same calculation interval then the running time of the lowest priority service is set to calculation interval minus the time the other services operate at full load. The running time of other services are set to the time they would operate at full load.

For systems with a thermal storage vessel, an additional pump may be required between the heat pump and vessel. The electrical energy consumed by this pump is taken as the maximum rated power multiplied by the heat pump running time in storage mode.

4.8 SPF calculation

SPF calculations are undertaken for both space and hot water services. These are summations of the hourly calculation intervals and are converted to efficiency for entry in the PCDB.

The space heating efficiency calculation is:

$$\eta_H = \frac{100x\ \Sigma Q_{H,gen,out(t)}}{\Sigma E_{H;gen;in(t)} + \Sigma Q_{H,gen,bu,out} + \Sigma E_{gen;in;LR0(t)} + \Sigma E_{gen;in;aux(t)}} \quad (\%) \qquad \textbf{(22)}$$

For reference (not used in this method), the fraction of space heating supplied by back-up is:

$$f_{bu} = \frac{\Sigma Q_{H,gen,bu,out(t)}}{\Sigma Q_{H,gen,bu,out(t)} + \Sigma Q_{H,gen,out(t)}} \quad (-) \qquad \textbf{(23)}$$

The water heating efficiency calculation for Service Provisions categories i - iii (for category iv - see Section 4.2) is:

$$\eta_W = \frac{100\ x\ \Sigma Q_{W,gen,out(t)}}{\Sigma E_{W;gen;in(t)} + \Sigma Q_{W,gen,bu,out(t)}} \quad (\%) \qquad \textbf{(24)}$$

Note 1: $Q_{H,gen,out}$ and $Q_{W,gen,out}$ both include back-up direct-electric energy
Note 2: $Q_{W,gen,out}$ implicitly includes the hot water vessel heat loss, that is, 0.54 x $Q_{WS,ls,24}$ x t_{ci} / 24 (see section 4.3).

4.8.1 Input test data utilisation

The calculation method enables the calculation of SPF datasets for use by SAP at design flow temperatures of 35°C, 45°C, 55°C, 58°C and 65°C, however, this requires two EN14825 test datasets (at different “low” and “high” flow temperature conditions), see *Appendix A - Category 1), 2), 6), 7) heat pumps, Service Provisions i, ii, iii*, for further details.

Only two EN14825 test datasets can be used by the calculation method; if only one is submitted, then only one SPF dataset will be calculated and entered in the PCDB. The exception is where a 55°C test dataset is submitted, in this case an SPF dataset for a design flow temperature of 58°C (SAP 2016 default flow temperature) will also be calculated.

If a SAP assessor obtains satisfactory evidence confirming a dwelling's emitter system design flow temperature is in-between those held in the PCDB, SAP 2016 software can interpolate between calculated SPF datasets held in the PCDB. However, this requires that there are two datasets with a difference in design flow temperature of ≤10°C.

4.8.2 Thermal storage vessels

If the system includes a thermal storage vessel the efficiencies are calculated as follows; the space heating efficiency calculation including back-up is:

$$\eta_H = \frac{100x\ \Sigma Q_{S,gen,out(t)}}{\Sigma E_{S;gen;in} + \Sigma Q_{S,gen,bu,out} + \Sigma E_{gen;in;LR0} + \Sigma E_{gen;in;aux} + \Sigma E_{S,gen,in,aux}} \quad (\%) \qquad \mathbf{(25)}$$

Note: $\Sigma E_{S,gen,in,aux}$ is auxiliary electrical consumption of the pump between the thermal storage vessel and heat pump.

For reference (not used in this method), the fraction for space heating supplied by back-up heating is:

$$f_{bu} = \frac{\Sigma Q_{S,gen,bu,out(t)}}{\Sigma Q_{S,gen,bu,out(t)} + \Sigma Q_{S,gen,out(t)}} \quad (-) \qquad \mathbf{(26)}$$

The water heating efficiency calculation including back-up is:

$$\eta_W = \frac{100\ x\ \Sigma Q_{S,gen,out(t)}}{\Sigma E_{S;gen;in} + \Sigma Q_{S,gen,bu,out}} \quad (\%) \qquad \mathbf{(27)}$$

APPENDIX A – EXHAUST AIR HEAT PUMP OVERVENTILATION

Heat pumps with mechanical ventilation are tested at two or three different air flow rates as explained in SAP 2012 Section N2.1 and Section 3.1 of this document. If the required rate for the dwelling, SAP Equation N1, is less than the lowest air flow rate for which data is provided in the database record for the heat pump, the mechanical ventilation is assumed to operate at the required rate during the non-heat pump operation and at the lowest rate in the database record for the heat pump during heat pump operation hours. This will change the building infiltration rate calculation (step e) below).

a) Obtain from the heat pump record the run hours (h_{hp}) applicable to the system exhaust air throughput for the dwelling, after applying linear interpolation based on the plant size ratio and system air throughput, rounding h_{hp} to the nearest integer value. Run hours are the total number of hours per year that the heat pump operates to achieve that heat output required by the building.

b) Obtain from the MEV/MVHR database record the specific fan power (SFP) for the duct type and number of wet rooms. If data is not listed for the duct type or number of wet rooms use the default values in SAP Table 4g.

c) Calculate the heat pump over-ventilation ratio R_{hp} using equation (N2). This is the ratio of the air flow through the ventilation system allowing for the operational requirement of the heat pump, to that which would apply for an equivalent ventilation system without a heat pump.

If the lowest air flow rate in the heat pump database record (in l/s) is less than the throughput for the dwelling from SAP Equation (N1), R_{hp} = 1; otherwise[42]:

$$R_{hp} = \text{lowest air flow rate (l/s)} \times 3.6 \div [(23a) \times (5)] \qquad \text{(N2)}$$

[42] The SAP specification limits the over-ventilation ratio (R_{hp}) to a maximum of 2. (23a) is a SAP reference to the "System Throughput" of the ventilation system in ach/hour; (5) is a SAP reference to the dwelling volume in m^3.

d) Calculate the annual electrical fan consumption (SAP reference (230a)) according to SAP Equation (N3) in kWh per year:

$$(230a) = (5) \times SFP \times \text{Fan in-use factor} \times (23a) \times R_{hp} \times (8760 - h_{hp}) \div 3600 \quad (N3)$$

e) Obtain the mechanical ventilation throughput factor, F_{mv}, from equation (N4) for calculation of worksheet (SAP reference (23b)):

$$F_{mv} = [(8760 - h_{hp}) + (R_{hp} \times h_{hp})] \div 8760 \quad (N4)$$

Note: The above is not implemented as an iterative procedure. Instead:

- set F_{mv} = 1 and calculate the ventilation loss rate and PSR
- obtain F_{mv} from equation (N4)
- re-calculate the ventilation loss rate and PSR, and apply this Appendix without further change to F_{mv} or R_{hp}.

APPENDIX B – REVISED SAP TABLE N5

Plant size ratio	Number of days operating at the hours shown by the first subscript instead of that of the second		
	$N_{24,16}$	$N_{24,9}$	$N_{16,9}$
0.1	67	166	1
0.2	62	156	4
0.3	55	137	12
0.4	48	120	12
0.5	37	91	31
0.6	27	68	35
0.7	14	36	47
0.8	7	19	50
0.9	4	10	35
1	2	6	24
1.1	1	3	16
1.2	1	2	9
1.3	0	0	9
1.4	0	0	5
1.5	0	0	3
1.6	0	0	3
1.7	0	0	1
1.8 or more	0	0	0
Use linear interpolation for intermediate values of plant size ratio, rounding the result to the nearest whole number of days.			

Revised SAP Table N5 - Additional days at longer heating duration for variable heating

Revised SAP Table N5 for implementation in SAP 2016.

APPENDIX C – SAP TABLE N2

See SAP 2016 specification.

APPENDIX D - TEST DATA REQUIREMENTS

In order to enter heat pump performance data in the SAP PCDB, the following test data is required with reference to the heat pump category and service provision. All test data must be supplied within a test report that is prepared in accordance with the test standard requirements.

Category 1), 2), 6), 7) heat pumps

Service Provisions i, ii, iii

Complete EN14825 test report to average climate for whichever temperature application is selected by manufacturer (see Table D1 and D2). To date, heat pumps entered in the PCDB have been supplied with 35°C, 45°C and 55°C (design flow) temperature application data, i.e. low, medium and high temperature applications. However, this revised method does not require medium (45°C) temperature test data, since calculated SPFs are determined using hourly interpolation between “low” and “high” temperature test results only, these are nominally 35°C and 55°C.

Acceptance of very high temperature (65°C) heat pump data will now be supported, meaning in this case that “high” temperature test data used within the method will instead be 65°C. In this case, the calculation of SPF at 45°C and 55°C will be determined using 35°C and 65°C test data. It will not be possible to use SPFs calculated at 65°C within SAP software until the SAP 2016 update.

A default design flow temperature of 58°C will be added for the SAP 2016 update. This must be used by SAP assessors when documentation in support of lower temperature design flow temperatures is inadequate[43]. The SPF at 58°C will be calculated using either 55°C or 65°C test data, whichever is submitted as “high” temperature test data.

[43] see: wwww.ncm-pcdb.org.uk/sap/lowtemperatureheating

For variable capacity heat pumps, EN14511 standard rating condition (7°C/6°C) must be provided at 35°C and 55°C conditions (or 65°C if a very high temperature heat pump) in all cases, unless a low temperature heat pump where only 35°C data is required.

Note: A suitable definition for solar-assisted heat pumps (Category 8) has not yet been proposed, hence these will be assumed as Category 2) heat pumps for the interim.

EN14825 - AVERAGE CLIMATE CONDITIONS – LOW TEMPERATURE APPLICATION									
Standard rating condition capacity (EN14511, in kW)									
Rated air or brine flow rate (m^3/hr)									
Condition	Part load ratio (%)	Source temperature during test – dry (wet) bulb (°C)			Water outlet temperature during test (°C) ***[delete column as appropriate]***		Capacity (kW)	Coefficient of Performance	Degradation coefficient (Cdh) ***[if unknown, enter 0.9]***
		Air-source heat pump	Ground-source heat pump	Exhaust-air heat pump	Fixed	Variable			
A	88	-7 (-8)	0	20 (12)	35	34			
B	54	2 (1)	0	20 (12)	35	30			
C	35	7 (6)	0	20 (12)	35	27			
D	15	12 (11)	0	20 (12)	35	24			
E			0	20 (12)	35				
F			0	20 (12)	35				

EN14825 - AVERAGE CLIMATE CONDITIONS – MEDIUM TEMPERATURE APPLICATION									
Standard rating condition capacity (EN14511, in kW)									
Rated air or brine flow rate (m^3/hr)									
Condition	Part load ratio (%)	Source temperature during test – dry (wet) bulb (°C)			Water outlet temperature during test (°C) ***[delete column as appropriate]***		Capacity (kW)	Coefficient of Performance	Degradation coefficient (Cdh) ***[if unknown, enter 0.9]***
		Air-source heat pump	Ground-source heat pump	Exhaust-air heat pump	Fixed	Variable			
A	88	-7 (-8)	0	20 (12)	55	52			
B	54	2 (1)	0	20 (12)	55	42			
C	35	7 (6)	0	20 (12)	55	36			
D	15	12 (11)	0	20 (12)	55	30			
E			0	20 (12)	55				
F			0	20 (12)	55				

Table D1 - Required EN14825 test data[44]

[44] An entry will only appear in the PCDB at the (design) flow temperature for which the test results are provided.

NOTE: Fixed or Variable Capacity Control option test data will be accepted.

Power	**Unit**	**Value**
Crankcase heater mode	W	
Standby mode	W	
Off mode	W	

Table D2 - Other EN14825 test data

Power	**Unit**	**Value**
Maximum flow temperature (with no direct-electric assistance)	°C	
Minimum source temperature at which maximum flow temperature is achieved	°C	
For heat pump category 1 (GSHP): Manufacturer declared rated brine pump power. This pump must be included in the heat pump package, otherwise leave blank.	kW	
Heat pump category 6): Water (Direct/Open-loop: Ground water to water) AND Heat pump category 7): Water (Direct/Open-loop: Surface water to water) Manufacturer declared maximum rated pump power, even if this is a maximum from a range of pump options.	kW	

Table D3 - Other data

For service provision (i) and (ii), hot water vessel heat losses ($Q_{WS,ls,24}$) in kWh/day are declared by the heat pump manufacturer, being either a fixed specification for a vessel sold or integrated to the heat pump, i.e. combination heat pump, or a worse-case vessel specification. The heat loss for a 45K temperature difference between the vessel and its surroundings is tested in accordance with BS 1566 or EN 15332 or any equivalent standard and recorded in the PCDB. The standby loss tested in accordance with EN16147 is not relevant. The heat loss is used in the calculation of the hot water heating SPF.

If the hot water vessel is integrated within the heat pump, i.e. a combination heat pump, then the following is required:

- Volume (Litres)
- Surface area of heat exchanger or heat transfer area (m^2)
- Heat loss (kWh/day)

If the hot water vessel is not integrated within the heat pump, then the following is required:

- *Minimum* volume (litres) within the range of manufacturer specified vessels
- *Minimum* surface area of heat exchanger, or heat transfer area (m^2), within the range of manufacturer specified vessels
- *Maximum* heat loss (kWh/day) within the range of manufacturer specified vessels

If multiple storage vessel types are sold with the heat pump, the minimum specification must apply to all storage vessel types. For example, if a heat pump is sold with either a 150L vessel with $2m^2$ heat exchanger area and 1.5 kWh/day heat loss or a 250L vessel with $3m^2$ area and 2.5 kWh/day heat loss, the minimum specification would be 150L, $2m^2$, 2.5 kWh/day.

The manufacturer must also supply evidence regarding weather compensation control, if present, and hot water synchronised controls - see Section 3.1.8 and 3.1.4.

Category 1), 2), 6), 7) heat pumps

Service Provisions iv (hot water heating only)

Complete EN16147 test report for standard conditions using load profile M. Provision for supplementary acceptance of load profile S or L is also provided, see Section 4.2.

Hot water vessel heat losses ($Q_{WS,ls,24}$) are declared by the heat pump manufacturer in kWh/day, tested in accordance with BS1566 or EN15332 or any equivalent standard, being either a fixed specification for a vessel sold or integrated to the heat pump, or a worse-case vessel specification - see Section 4.2.

If the hot water vessel is integrated within the heat pump, then the following is required:

- Volume (Litres)
- Surface area of heat exchanger or heat transfer area (m^2)
- Heat loss (kWh/day)

If the hot water vessel is not integrated within the heat pump, then the following declarations are required:

- *Minimum* volume (litres) within the range of manufacturer specified vessels – this can be no more than 50 Litres less than the vessel volume used during EN16147 tests to load profile M and a minimum 115 Litres (unless supporting evidence is provided) – see Section 4.2.
- *Minimum* surface area of heat exchanger, or heat transfer area (m^2), within the range of manufacturer specified vessels – this must be the area specified within the minimum volume vessel.
- *Maximum* heat loss (kWh/day) within the range of manufacturer specified vessels.

If multiple storage vessel types are sold with the heat pump, the minimum specification must apply to all storage vessel types. For example, if a heat pump is sold with either a 200L vessel with 2.4m^2 heat exchanger area and 1.5 kWh/day heat loss or a 250L vessel with 3m^2 area and 2.5 kWh/day heat loss (the vessel used for testing), the minimum specification would be 200L, 2.4m^2, 2.5 kWh/day [Note: 200 Litres would be the minimum volume in this case, owing to the 50 Litre restriction above].

The declared minimum hot water vessel volume entered in the PCDB can be up to 50 litres less than that tested and a minimum of 115 Litres, unless expressly advised by the manufacturer (with supporting evidence). The value of $Q_{WS,ls,24}$ for entry in the PCDB is declared by the manufacturer and may be up to 25% larger than the vessel used during the EN16147 test, it will not be used within the efficiency calculation.

Category 3) - 5) heat pumps

Service Provisions i, ii, iii

Complete EN14825 test report to average climate for whichever temperature application is selected by manufacturer (Table D1 and D2). For the avoidance of doubt, the source temperature is 20°C. To date, heat pumps entered in the PCDB have been supplied with 35°C, 45°C and 55°C temperature application data, i.e. low, medium and high temperature applications. However, this revised method does not require medium (45°C) temperature test data, since calculated SPFs are determined using 35°C and 55°C test results based on sink temperature required. Fixed or Variable Capacity Control option test data will be accepted.

Two or three air flow rates, at which the combined product system was tested, including the minimum, must be provided in the test report. This means that two or three EN14825 test datasets will be required.

For variable capacity heat pumps, EN14511 standard rating condition (7°C/6°C) must be provided at 35°C and 55°C conditions (or 65°C if a very high temperature heat pump) in all cases, unless a low temperature heat pump where only 35°C data is required. These should be provided at the minimum air flow rate used for EN14825 tests.

For Category 3) heat pumps, the performance of the MEV system, with heat pump inactive, must also be tested in accordance with the test method: *'SAP PCDB: Test method for central exhaust ventilation system packages used in a single dwelling'.* This must represent operation of the package when there is zero heat demand, but it is otherwise operational.

For Category 4) heat pumps, the performance of the MVHR system, with heat pump inactive, must also be tested in accordance with the test method: '*TESTM:01 - SAP 2012 Test method for Centralised Mechanical Supply and Extract Ventilation System Packages with heat recovery used in a single dwelling.'* This must represent operation of the package when there is zero heat demand, but it is otherwise operational.

For Heat Pump Category 5), the performance is determined as above for Category 3) or 4) heat pumps as appropriate.

Note: The SAP calculation imposes an over-ventilation ratio (R_{hp}) limit of 2, which corresponds to the assessed dwelling's volume.

For service provision (i) and (ii), hot water vessel heat losses ($Q_{WS,ls,24}$) in kWh/day are declared by the heat pump manufacturer, being either a fixed specification for a vessel sold or integrated to the heat pump, i.e. combination heat pump, or a worse-case vessel specification. The heat loss for a 45K temperature difference between the hot water vessel and its surroundings are tested in accordance with BS 1566 or EN 15332 or any equivalent standard and recorded in the PCDB. The heat loss tested in accordance with

EN16147 is not relevant. The heat loss is used in the calculation of the hot water heating SPF.

If the hot water vessel is integrated within the heat pump, i.e. a combination heat pump, then the following is required:

- Volume (Litres)
- Surface area of heat exchanger or heat transfer area (m^2)
- Heat loss (kWh/day)

If the hot water vessel is not integrated within the heat pump, then the following is required:

- *Minimum* volume (litres) within the range of manufacturer specified vessels
- *Minimum* surface area of heat exchanger, or heat transfer area (m^2), within the range of manufacturer specified vessels
- *Maximum* heat loss (kWh/day) within the range of manufacturer specified vessels

If multiple storage vessel types are sold with the heat pump, the minimum specification must apply to all storage vessel types. For example, if a heat pump is sold with either a 150L vessel with $2m^2$ heat exchanger area and 1.5 kWh/day heat loss or a 250L vessel with $3m^2$ area and 2.5 kWh/day heat loss, the minimum specification would be 150L, $2m^2$, 2.5 kWh/day.

The manufacturer must also supply evidence regarding weather compensation control, if present, and hot water synchronised controls - see Section 3.1.8 and 3.1.4.

Category 3) – 5) heat pumps

Service Provisions iv (hot water heating only)

Complete EN16147 test report for standard conditions using load profile M. For the avoidance of doubt, the source temperature is 20°C and the product must be a ducted-type[45]. The manufacturer's claimed maximum External Static Pressure must be declared. Any additional fans necessary for operation of the product system must be included within

[45] Otherwise the requirements of Building Regulations: Approved Document Part F – Ventilation cannot be satisfied.

test measurements. Provision for supplementary acceptance of load profile S or L is also provided, see Section 4.2.

The unit must be tested at an airflow rate that represents the minimum number of wet rooms supported by the unit, as specified by the Manufacturer. For example, if the unit operates with no less than three wet rooms, but up to six, then the test airflow rate is 37 l/s. This test airflow rate is derived in accordance with Building Regulations - Ventilation: Approved Document F; in this case the “minimum high rate” for three wet rooms, or “K+3”, is used, i.e. 1*13 + 3*8 = 37 l/s.

The airflow during the test must be continuous, not intermittent, even if the heat pump compressor operates intermittently. Likewise, for compliance with Building Regulations as a fixed ventilation appliance, the airflow must also be continuous during commissioned operation.

For Category 3) heat pumps, the performance of the MEV system, with heat pump inactive, must also be tested in accordance with the test method: *‘SAP PCDB: Test method for central exhaust ventilation system packages used in a single dwelling’.* This must represent operation of the package when there is zero heat demand, but it is otherwise operational. The tested airflow rate should be a range that represents the declared minimum (see above) and the maximum achievable.

For Category 4) heat pumps, the performance of the MVHR system, with heat pump inactive, must also be tested in accordance with the test method: ‘*TESTM:01 - SAP 2012 Test method for Centralised Mechanical Supply and Extract Ventilation System Packages with heat recovery used in a single dwelling.’* This must represent operation of the package when there is zero heat demand, but it is otherwise operational. The tested airflow rate should be a range that represents the declared minimum (see above) and the maximum achievable.

For Heat Pump Category 5), the performance is determined as above for Category 3) or 4) heat pumps as appropriate.

Note: The SAP calculation imposes an over-ventilation ratio (R_{hp}) limit of 2, which corresponds to the assessed dwelling's volume.

Hot water vessel heat losses ($Q_{WS,ls,24}$) are declared by the heat pump manufacturer in kWh/day, tested in accordance with BS1566 or EN15332 or any equivalent standard, being either a fixed specification for a vessel sold or integrated to the heat pump, or a worse-case vessel specification - see Section 4.2.

If the hot water vessel is integrated within the heat pump, then the following is required:

- Volume (Litres)
- Surface area of heat exchanger or heat transfer area (m^2)
- Heat loss (kWh/day)

If the hot water vessel is not integrated within the heat pump, then the following declarations are required:

- *Minimum* volume (litres) within the range of manufacturer specified vessels – this can be no more than 50 Litres less than the vessel volume used during EN16147 tests to load profile M and a minimum 115 Litres (unless supporting evidence is provided) – see Section 4.2.
- *Minimum* surface area of heat exchanger, or heat transfer area (m^2), within the range of manufacturer specified vessels – this must be the area specified within the minimum volume vessel.
- *Maximum* heat loss (kWh/day) within the range of manufacturer specified vessels.

If multiple storage vessel types are sold with the heat pump, the minimum specification must apply to all storage vessel types. For example, if a heat pump is sold with either a 200L vessel with $2.4m^2$ heat exchanger area and 1.5 kWh/day heat loss or a 250L vessel with $3m^2$ area and 2.5 kWh/day heat loss (the vessel used for testing), the minimum specification would be 200L, $2.4m^2$, 2.5 kWh/day [Note: 200 Litres would be the minimum volume in this case, owing to the 50 Litre restriction above].

The declared minimum hot water vessel volume entered in the PCDB can be up to 50 litres less than that tested and a minimum of 115 Litres, unless expressly advised by the manufacturer (with supporting evidence). The value of $Q_{WS,ls,24}$ for entry in the PCDB is declared by the manufacturer and may be up to 25% larger than the vessel used during the EN16147 test, it will not be used within the efficiency calculation.

Thermal storage

If heat pump package incorporates a thermal storage vessel, i.e. primary water/non-potable water, and its effect is to be included within the calculation, the following details are required:

- EN15332 or equivalent test measuring heat loss over 24 hours for a constant temperature difference of 45°C with the surroundings
- Control setpoint temperature of thermal storage vessel (^{O}C)
- Control temperature deadband width of vessel thermostat (^{O}C)
- Vessel volume (l)
- Description of the control strategy