Calculation procedure for the SAP Appendix Q process for electrically driven heat pumps

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1   Introduction

The document describes the calculations in Appendix Q for SAP 9.82 for electrical heat pumps whose thermal performance has been verified by laboratory tests to EN14511-2 and/or prEN255-3 which are used to estimate its predicted annual performance in CEN 15316-4-2.

Allowable heat pumps are grouped by heat source:

1. Air-Source Heat Pump *(air/water)* – Keyword *Air*
2. Ground-Source Heat Pump (*water/water*) – Keyword *Ground*
3. Exhaust Air-Source Heat Pump with Whole House Mechanical Extract Ventilation - Exhaust air only *(air/water)* – Keyword *Exhaust air MEV*
4. Exhaust Air-Source Heat Pump with Whole House Mechanical Extract Ventilation - Exhaust air plus mixed ambient air *(air/water)* – Keyword *Exhaust air mix*
5. Exhaust Air-Source Heat Pump with Whole House Mechanical Ventilation with Heat Recovery *(air/air)* – Keyword *Exhaust air MVHR*

Mixed source systems are reflected in the results by EN 15316-4-2 referencing a source temperature that is representative of the mixture.

Exhaust air heat pumps are linked to whole house mechanical extract ventilation (MEV) or mechanical ventilation with heat recovery (MVHR). Mixed air exhaust heat pumps are linked to MEV.

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

2   Definitions

CEN15316-4-2 and the associated SAP wrapper produce the following variables for use in the appendix Q procedure (table 1)

Table 1 CEN15316-4-2 output variables for appendix Q

Location Row/ column	Description	Units	Symbol in this document
1	Unique index (101 or greater)	N/A	
2	Make	N/A	
3	Model name	N/A	
4	Qualifier	N/A	
5	Data source (1= UKAS or equivalent 2 = MCS accredited after 1 Nov 2009 3 = MCS accredited before 1 Nov 2009)	N/A	
6	Cooling function (1 = yes else 0)		
7	Heat pump fuel code (see SAP table 12)	N/A	
8	Backup space heating fuel (SAP table 12)	N/A	
9	Backup space heating fuel efficiency		e_{bk}
10	Heat pump source (ground etc)		
11	Weather compensator included in results	Yes/No	
12	C/H circulator power included (Yes/No)	Yes/No	
13	Heating hours (24, 16, 11 or Variable = V)		
14	Domestic hot water class (code 1 to 5) 1 – integrated hot water vessel; 2 separate vessel but controlled and specified in the database; 3 provided by heat pump by unspecified vessel; 5 provided by a hot water only gas boiler 5 not provided by heat pump	1	
15	Hot water storage vessel volume	Litres	Vol_{cyl}
16	Declared storage vessel heat loss at 45K rise above ambient	kWh/day	Q_{cyl}
17	Vessel heat transfer area	m²	
18	Hot water controls synchronized	(Y/N)	
19	Water heating SPF inc backup and auxiliary	fraction	η_{hw}
For seven plant size ratios x three emitter type x up three air flow rate types			
20	Plant size ratio (Capacity/design heat loss)	Ratio	PSR
11	Emitter type (floor, radiators or convectors)	N/A	
22	Extract air flow rate	l/s	A
23	Heating capacity (maximum heat output for space heating – varies by emitter type)	kW	Q_{out}
24	Heating SPF includes auxiliary but excludes any backup heating	CoP	η_{sp}
25	Heat pump running hours per year	hours	h_p
For 19 different wet room configurations			
10 (E to X)	Excluding the kitchen; the number of wet rooms ducted	Wet rooms	N_{rm}
11 (E to X)	Specific fan power (rigid) at the above number of wet rooms	W per l/s	SFP
12 (E to X)	Specific fan power (flexible) at the above number of wet rooms	W per l/s	SFP
13 (E to X)	Heat exchanger efficiency (rigid) at the above number of wet rooms	%	η_{he}
14 (E to X)	Heat exchanger efficiency (flexible) at the above number of wet rooms	%	η_{he}

2.1 Coefficient of performance (CoP) definitions

Note the annual *hot water* CoP and the annual *space heating* CoP definitions are slightly different than the main results of CEN 15316:4-2 but still use the constituents from CEN 15316:4-2 to calculate them.

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

This is necessarily and deliberately different than the instantaneous definition in the submission document.

The water heating *divisor* includes any backup heat required to generate the hot water and to keep the cylinder warm but includes any auxiliary electricity used by other electronic components.

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

The space heating CoP *excludes* any *backup* heating but includes any auxiliary electricity used by other electronic components.

2.2 Heating definitions

The four types of heating are:

- Plant – from the heat pump
- Primary – from the main.heating system i.e. backup plus plant heating.
- Secondary – from a secondary source usually portable heaters or focal point fires.
- Backup – any shortfall in the primary heating not met by the heat pump

The amount specified in the SAPQ workbook is the plant heating fraction expressed as fraction of the total requirement. The amount of secondary heating is specified during the SAP Assessment and is currently forced to 10% for DER purposes.

The backup fraction is only applied to primary heating because the secondary heating is not related to times when the heating requirement exceeds the maximum heat output but related to focal point heating.

CEN 15316:4-2 calculates a back-up heating quantity for space and water heating. The backup space heating calculation of CEN 15316:4-2 is not used because it assumes 24 hour heating and is different than that used by other product classes (eg micro-cogeneration). The plant heating fraction calculation details are in appendix C.

3 Calculation Procedure

1. Obtain the following dwelling parameters from the dwelling assessment (table 1 and table 2)

Table 2 SAP parameters required

SAP parameter description	SAP notation	Symbol
All heat pumps		
Total floor area (m^2)	**box (5)**	tfa
Heat loss coefficient W/K	**box (37)**	Q_{loss}
Output from hot water kWh/year	**box (51)**	Q_{hw}
Heat Gains W	**box (66)**	G
Base temperature °C	**box (79)**	T_b
Fraction of heat from secondary/supplementary system must be 0.1 for DCR purposes (currently set to 0.1).	**box (82)**	f_s
Efficiency of main heating system **%** (SEDBUK or from Table 4a or 4b, adjusted where appropriate by the amount shown in the 'efficiency adjustment' column of Table 4c)	**box (83)**	e_{sp}
Efficiency of water heating system	**box (86)**	e_{hw}
Carbon dioxide emissions for main space heating (kg CO_2/year)	**box (101)**	C_{sp}
Carbon dioxide emissions for water heating (kg CO_2/year)	**box (103)**	C_{hw}
For exhaust air or mixed exhaust heat pumps (Air, MEV or MVHR)only		
Dwelling volume	**box (6)**	Vol
For exhaust air heat pumps with MVHR only		
The carbon dioxide emissions, kg/m², at the design or measured air leakage rate	**box (113)**	DC
Design or measured air leakage at 50 Pascal's, m³/m².h		q_{50}
The carbon dioxide emissions, kg/m², at the modified design or measured air leakage rate (q_{50}^{*})	**box (113)**	DC^{*}
Number of chimneys	**box (7)**	N_{ch}
Number of open flues	**box (8)**	N_{op}
Number of storeys	**n/a**	N_s
Number of sides sheltered	**box (20)**	N_{st}

Table 3 Other parameters obtained during the assessment required

Parameter description	Appendix Q box
For heat pumps with water heating type (1 or 2)	
Storage vessel volume, litres (Vol_{cyl})	**Box Q02**
Declared loss kWh/day (Q_{cyl})	**Box Q03**
Storage vessel heat transfer area (m²)	**Box Q04**
All heat pump types	
Main heat emitter type (radiators, under floor etc)	**Box Q05**
Are the controls for weather compensation installed, Yes or No?	**Box Q06**
For exhaust air heat pumps (MEV or MVHR)only	
Ductwork type (rigid or flexible and details of any ductwork outside the dwelling insulation)	**Box Q08**
Ductwork configuration: Excluding the kitchen how many wet rooms are ducted? Data provided for 1 to 7 additional wet rooms.	**Box Q09**

It is important that the following water heating systems are entered into the *SAP calculator* as follows because savings are calculated relative to that system.

- Electric heat pump with cylinder and heat loss as those displayed in Q02 and Q03 - for Integrated hot water vessel (DHW Class 1) or separated hot water vessel that is the same as specified (DHW Class 2)
- Electric heat pump with cylinder and heat loss as installed – for unspecified hot water vessel (DHW Class 3) or vessel not the same as specified (downgraded DHW Class 2 to DHW Class 3)
- Gas multiple-point water heater – for gas hot water only boilers (DHW Class 4)
- The hot water system installed – for hot water not provided by heat pump nor gas multiple heater (DHW Class 5)

2. *Exhaust air* or *mixed air and exhaust* heat pumps tests may have been carried out at *two* or *three* different air flow rates, so first obtain the air throughput (n_{mech}). For MVHR systems this requires an iterative process of twenty steps (see Appendix A for details) and for MEV it is 0.5 dwelling air changes per hour. This is the same as the established Appendix Q procedure for MEV and MVHR systems without a heat pump.

Calculate the air flow rate in l/s from the air throughput in dwelling volume air change per air as follows:

Air flow rate in l/s: $A = \dfrac{1000 \times n_{mech}}{3600 \times vol}$

Obtain the values of the variables listed below at each of the seven the plant size ratios (PSRs) for the *calculated* air flow; by linear interpolation of the values at the test rates immediately above and below the calculated rate.   If the calculated flow rate is higher than the highest test rate, use the values at the highest test rate and if lower than the lowest test rate, used the values at the lowest test rate..

- the CoP for space heating (η_{sp})
- heat pump running hours per year (h_{hp})

If the calculated flow rate is lower the lowest test rate, the dwelling will be over ventilated and a further adjustment is required to take account of the extra losses and increased ventilation as follows. Otherwise set $V_{ex} = 0$.

a) The required system throughput = n_{mech} x 1000/3600 where n_{mech} is the system throughput in air changes per hour. For MEV the throughput is 0.5 for MVHR see Appendix A.

b) Over-ventilation factor F_{ov} = lowest test rate ÷ required system throughput. *If the over-ventilation factor is greater than 2* the appendix Q procedure is not valid so revert to the default heat pump calculation (appendix G of SAP).

c) The extra ventilation loss V_{ex}

   For MVHR
   $V_{ex} = (F_{ov} - 1)$ x n_{mech} x 0.33 x vol x $(1 - ^* \eta_{he} \times F_{inuse,he})$,

   where vol is dwelling vol in m^3 and where η_{he} and $F_{inuse,he}$ is the heat exchanger efficiency and in-use factor of the MVHR.

   Note the extra ventilation loss is over that for the case of the required rate with the MVHR properties as stated in the database sheet not that the default MVHR properties).

   (Source SAP line (23) x line (36) for over ventilated building rate – value for required building rate $= [(22a)^*-(22)] \times [1 - (22b) \div 100] \times 0.33 \times (6)$)

   For MEV $V_{ex} = (1 - F_{ov})$ x 0.25 x 0.33 x dwelling volume

   (Source: The SAP calculation is based on a throughput of 0.5 air changes per hour through the mechanical system, plus infiltration (page 11 SAP document) and the effective rate is calculated at line 23b; that is $0.25 + (22)$.

   And so SAP assumes the MEV system throughput of 0.5 air changes per hour contributes only half the amount (0.25 changes per hour) to the building infiltration rate). The same assumption is made when calculating the extra ventilation loss due to over ventilation, that is, the

increase building rate is based on half the increased in the system rate).

d) If the MEV or MVHR when tested without the heat pump was tested at higher rate than the standard rate for the stated number of wet rooms, repeat c) using an over-ventilation factor of the test rate ÷ standard test rate and set the result, V_{ex}, to V_{ex1}. Otherwise $V_{ex1} = 0$.

e) The average increase in ventilation loss = $(8760 - h_{hp}) \times V_{ex1} + h_{hp} \times V_{ex}$ where h_{hp} is the heat pump running hours (see main part of step 2).

f) Calculate the revised heat loss by adding the result to the unrevised loss obtained in Step 1.

3. Calculate the plant size ratio using the heat loss coefficient (Q_{loss}) obtained in step 1 and the heating capacity (Q_{loss}) which will vary by emitter type specified in the AQ assessment.

$$PSR = \frac{Q_{out}(kW)}{Q_{loss}(W/C) \times 24.2(C)}$$

24.2°C is the whole house inside/outside temperature difference under design conditions (i.e 19.2 – -5) (source: new boiler sizing method where the bedrooms, kitchens and halls design temperature is 18°C and living room is 21°C)

If the *PSR* is outside the valid range abandon the appendix Q process. Current valid range is 0.2 to 2.0. The low values are for the MVHR systems that may only contribute a small amount of heat, that is, they may not be the main heating system but this is simplest way to deal with them in appendix Q.

Obtain the following values from table C3 and C4 (appendix C).

- plant heating fraction (f_{pl})
- heating days instead at 16 hours instead of 9 ($N_{16,9}$)
- heating days instead at 24 hours instead of 9 ($N_{24,9}$)
- heating days instead at 24 hours instead of 14 ($N_{24,16}$)

4. Obtain the following values at the plant size ratio immediately above and below the calculated PSR to obtain by linear interpolation the values at the calculated PSR.

- the CoP for space heating η_{sp}
- heat pump running hours per year (h_{hp})

5. Calculate the *unrevised* values of the following (i.e before the selected heat pump parameters are applied):

Heating requirement (kWh/year) $Q_{sp} = DD(T_b) \times Q_{loss} \times 0.024$
(source sap box 81 line)

(*DD(T)* is the degree-day function at base temperature, T_b, see SAP table 10).

Primary heating consumption (kWh/year) $Q_{sp1} = \dfrac{100 \times Q_{sp} \times (1 - f_s)}{e_{sp}}$
(source sap line box 55)

Water heating consumption (kWh/year) $Q_{hw1} = \dfrac{100 \times Q_{hw}}{e_{hw}}$
(source sap line box 86a)

Primary heating carbon factor (kg CO_2/kWh) $CF_{sp} = \dfrac{C_{sp}}{Q_{sp1}}$
(source sap line box 101)

Water heating carbon factor (kg CO_2/kWh) $CF_{hw} = \dfrac{C_{hw}}{Q_{hw1}}$
(source sap line box 103)

Mean internal temperature (living area)

$$MIT_1 = \frac{(68 \times T_{16}) + (170 \times T_9)}{238}$$

T_{16} and T_9 are the mean internal temperatures obtained from table 9 of SAP for 34 weeks of weekends and weekdays respectively (see appendix B). The temperatures depend on the heating system's responsiveness (or heating type) and heat loss parameter (heat loss ÷ total floor area). The heating type in turn depends on the emitter type as noted in table 4.

Table 4 Emitter parameters

Emitter type	Radiators	Under floor pipes in insulated timber	Under floor pipes in concrete slab	Under floor pipes in screed above insulation	Convectors
SAP Heating type number	1	1	4	2	1
Weather compensator benefit in SAP 2005	Yes	No	No	No	No

6. For systems with whole house mechanical ventilation systems (MEV) *only* calculate the *unrevised* fan consumption (i.e. the default MEV case).

Fan electricity consumption kWh/yr $Q_{fan} = 8760 \times 0.5 \times 0.8 \times 2.5 \times vol / 3600$

(8760 is the number of hours per year, 3600 is the number of seconds per hour, 0.5 air changes/hour is throughput for MEV system, 0.8 W/(l/s) is the specific fan power, 2.5 is utilisation factor and *vol* is the dwelling volume in m^3.)

7. For systems with a whole house mechanical ventilation with heat recovery (MVHR) *only* calculate the *unrevised* fan consumption (i.e. the default MVHR case)

Fan electricity consumption kWh/yr

$$Q_{fan} = 8760 \times n_{mech} \times 2 \times 2.5 \times vol / 3600$$

NB 12.2 = 8760/3600 x 2 x 2.5 and 2 and 2.5 are the default SFP is W per l/s and the in-use factor respectively. The mechanical throughput (n_{mech}) in dwelling air changes per hour is 0.5 for MEV. For MVHR see appendix A. 8760 is the number of hours per year and 3600 is the number seconds per hour.

(Source first part of formula C44 in MVHR AQ SAP 9.82 sheet shown in red =(12.2-2.44xSFP)*vol*n_{mech}+(n*_{mech}-n_{mech})x12.2xVol)

8. Calculate the *revised* heat gains, if any;

For a heat pump with a HW only gas boiler (DHW class 4): obtain the heat gains (box 66 in Watts), cylinder loss ($L_{st,c}$ in kWh/yr) and combi loss (L_c kWh/yr) for the combi boiler selected or *for a heat pump with MEV/MVHR over ventilating* calculated the following:

Revised gains

$$G^*(\text{in W}) = G(\text{in W}) + \frac{(0.8 \times L_{st,c} + 0.25 \times L_c)}{8.76}$$

For combi boilers *without* a keep hot facility the combi loss must be scale by: the lower value of (25*N_{occ}+38)/100 and 1. (N_{occ} is the number occupants calculated from the total floor area – see SAP table 1 for more details).

Revised useful gain

$$G_u^* = G^* \times e^{(-18 \times G^* / Q_{loss}^*)}$$

$$T_{ch} = (\frac{G_u^*}{Q_{loss}^*} - \frac{G_u}{Q_{loss}}) \times (1 + (0.2 \times R))$$

(R is the responsiveness of the emitter type in SAP table 4d)

When DHW class is: 1, 2, 3 or 5 then $L_{st,c} = L_c = 0$

When not over ventilating $Q^*_{loss} = Q_{loss}$

When DHW class is: 1, 2, 3 or 5 *and* not over ventilating

$$T_{ch} = 0$$

For all cases calculate the revised mean internal temperature and revised total heating requirement (i.e after the heat pump parameters are applied).

Revised mean internal temperature (°C)

$$MIT^* = \frac{(N_{24,16} + N_{24,9}) \times T_{24} + (68 - N_{24,16} + N_{16,9}) \times T_{16} + (170 - N_{16,9} - N_{24,9}) \times T_9}{238}$$

For T_{16} and T_9 see the last part of step 5. $T_{24} = 21$ °C and so assumes a room thermostat and/or TRVs is present as required by Building Regulations.

Heating requirement (kWh/year)

$$Q^*_{sp} = DD(T_b + MIT^* - MIT - T_{ch}) \times Q_{loss} \times 0.024$$

(source SAP line box 81)

9. Calculate the adjusted *CoPs* including the any weather compensation factors and in-use factors.

   In-use factors are:

   - Space heating $F_{inuse,sp} = 0.95$ (or -5%)
   - DHW class 1 or 2 $F_{inuse,hw} = 0.95$ (or -5%)
   - DHW class 3 $F_{inuse,hw} = 0.60$ (or -40%)
   - DHW class 4 or 5 irrelevant

   For DHW class 2 if the installed vessel is not at least as good as specified for heat pump then $F_{inuse,hw} = 0.6$ applies. This occurs if the *installed* vessel heat loss is higher or the heat transfer area or volume is lower than the values for the *specified* vessel.

   Obtain η_{hw}: for DHW class 1,2 or 3 it is the *CoP* of the heat pump and for DHW class 4 it is the hot water efficiency of the gas combi boiler multiplied by 100. DHW class 5 does not apply.

$$\eta_{hw}^* = \eta_{hw} \times F_{inuse,hw}$$

For DHW Class 1, 2 or 3 a minimum efficiency revised efficiency of 100%.

If the weather compensator effect is *not included* in the *test* results *and radiators* are specified then revise the *CoP* calculated in step 4 according to SAP 2005 weather compensation rules; eg adjustments only apply to radiators and not convectors or under floor emitters.

Heating COP $\eta_{sp}^* = \dfrac{0.75}{0.70} \times \eta_{sp} \times F_{inuse,sp}$

If radiators are not specified *or* if test results do *include* the weather compensation effect:

Heating COP $\eta_{sp}^* = \eta_{sp} \times F_{inuse,sp}$

Calculate the:

Back-up fraction $f_{bk} = (1 - f_{pl})$

(f_{pl} is the primary heating fraction (see appendix C, table C4) and f_s is the secondary heating fraction currently fixed at 0.1).

Revised primary heating consumption (kWh/yr)
$$Q_{sp2} = \frac{Q_{sp}^* \times (1 - f_{bk}) \times (1 - f_s)}{\eta_{sp}^*}$$

Backup heating consumption (kWh/yr)
$$Q_{bk} = \frac{100 \times Q_{sp}^* \times f_{bk} \times (1 - f_s)}{e_{bk}}$$

For DWH Class 1, 2 and 3 the revised water heating consumption (kWh/yr)

$$Q_{hw2} = \frac{Q_{hw}}{\eta_{hw}^*} - \frac{0.6 \times Q_{cyl} \times 365}{\eta_{hw}^*}$$

For DWH Class 4 the revised water heating consumption (kWh/yr)

$$Q_{hw2} = \frac{Q_{hw}}{\eta_{hw}} + \frac{C_c + C_{st,c}}{\eta_{hw}}$$

For DWH Class 5 the revised hot water heating consumption is the same as the original ie. 100 x **box (51)/box(86).**

0.6 is the temperature factor in table 2b of SAP and Q_{cyl} is the manufacturer's declared storage vessel heat loss in kWh/day for temperature differential of 45K). Note Q_{hw}, SAP Box (51), already contains "$0.6 \times Q_{cyl} \times 365$" hence the latter subtraction. C_c and $C_{st,c}$ are the combi loss and combi storage loss for DHW code 4.

10. For heat pumps with a whole house mechanical extract ventilation (MEV) obtain the *specific fan power (SFP)* for the number of wet rooms excluding one kitchen and duct type and calculate the revised fan consumption.

Revised fan electricity consumption
$$Q_{fan}^* = F_{ov1} \times (8760 - h_{hp}) \times 0.5 \times SFP \times F_{inuse,fan} \times vol / 3600$$

The fan in-use factor ($F_{inuse,fan}$) is 1.4 for rigid, 1.7 for flexible ductwork and 2.5 if a SPF is not provided for duct type/wet room number configuration specified. h_{hp} is the heat pump running hours per year (see step 4), 8760 is the number of hours per year and 3600 is the number of seconds per hour. F_{ov1} is the over venting factor when heat is not running in step 2(d).

11. For heat pumps with MVHR obtained the *specific fan power* and *heat exchanger efficiency* for the number of wet rooms excluding one kitchen and duct type and calculate the *revised* fan consumption.

Revised fan electricity consumption is:

$$Q_{fan}^* = F_{ov1} \times (8760 - h_{hp}) \times n_{mech} \times SFP \times F_{inuse,fan} \times vol \div 3600$$
$$-F_{ov1} \times (8760 - h_{hp}) \times (n_{mech}^* - n_{mech}) \times 2 \times 2.5 \times vol \div 3600$$

The fan in-use factor $F_{inuse,fan}$ is 1.4 for rigid, 1.7 for flexible duct work and 2.5 if a SFP is not provided for duct type/wet room number required. n_{mech}^* is the revised system air throughput in changes in hour (see appendix A). F_{ov1} is the over venting factor when heat pump is not running in step 2(d).

Source: part of formula C44 in MVHR SAP 9.81 sheet shown in red
=(12.2-2.44*adj SFP)*vol*n_mech+(n'_mech-n_mech)*12.2*vol . Note 2.44 = 8760/3600 and 12.2 = 2.44 x 2.5 x 2 with 2.44 and 2 the default utilisation and SPF value.

12. For heat pumps with MVHR with a valid heat exchanger efficiency for the duct/wet room arrangement calculate the savings due to the heat exchanger efficiency being different than the default case as:

Heat exchanger efficiency saving in kWh per year:

$$\Delta Q_{hee} = (DC - DC^*) \times tfa \div CF(electricity)$$

DC and *DC** are, respectively, the carbon emission per m^2 obtained from the SAP calculator before and after entering the adjusted air pressure test value to account for the change in heat exchanger efficiency compared to that of the default heat exchanger efficiency.

For heat pump without MVHR $\Delta Q_{hee} = 0$

(Source: MVHR 9.82 sheet cell C44)

13. If the power of the central heating pump is included in the test results then set the amount:

c/h pump consumption kWh/yr $\Delta Q_{chP} = -130$ Otherwise $\Delta Q_{chP} = 0$

(source 130 kWh/yr is the SAP 2005 value assigned to c/h pumps)

14. Calculate the *following* carbon emissions and equivalent savings:

The *unrevised* emissions due to primary heating, water heating, central heating pump and fans (i.e. the default SAP heat pump)

$$C_{tot} = (CF_{sp} \times Q_{sp1}) + (CF_{hw} \times Q_{hw1}) + (CF_{ele} \times Q_{fan})$$

The savings (or penalty if negative) in carbon dioxide emissions compared to the heat pump selected in the main SAP calculator are:

$$\Delta C_{tot} = C_{tot} - (CF_{sp} \times Q_{sp2}) - (CF_{hw} \times Q_{hw2}) - CF_{el} \times (\Delta Q_{chp}^* + Q_{fan}^* - \Delta Q_{hee}) + (CF_{bk} \times Q_{bk})$$

Expressed in kWh of the heat of the heat pump fuel, electricity, the saving (or penalty if negative) is:

$$Q_{sav} = \frac{\Delta C_{tot}}{CF_{el}}$$

Appendix A – MVHR air throughput

Air throughput for whole house mechanical ventilation with heat recovery system (MVHR) involves a 20 step iterative process. This is the same process as in the MVHR 9.82 AQ workbooks.

The required data inputs obtained from the SAP calculator are:

Table A1 SAP parameters

Number of chimneys	**box (7)**	N_{ch}
Number of open flues	**box (8)**	N_{op}
Number of storeys		N_{st}
Number of sides sheltered	**box (20)**	N_s
Design or measured air leakage at 50 Pascal's, m³/m².h		q_{50}

Using the heat exchanger efficiency (η_{he}) found in the HP database expressed as a fraction and applicable to number wet rooms and duct type specified and the in-use factor ($F_{inuse,he}$) applicable to the duct insulation specified calculate the following in turn:

$$q_{50}^* = q_{50} - (10.76 \times n_{mech} - 20 \times n_{mech} \times \frac{(1-(\eta_{he} \times F_{inuse,he}))}{(1-(N_s \times 0.075))} \qquad 1$$

$$n_{adj}' = (\frac{q_{50}^*}{20} + \frac{(40 \times N_{ch}) + (20 \times N_{op})}{Vol}) \times (1 - N_s \times 0.075) \qquad 2$$

$$n_{min}^* = 0.5 - n_{adj}^* \quad \text{(if } n_{min}^* \text{ is negative set it to zero)} \qquad 3$$

$$n_{mech}^* = n_{min}^* \qquad 4$$

Restrict value of n_{mech}' to a maximum of 0.3 (1 storey) or 0.35 (2 or more).

$$q_{50}^* = q_{50} - (10.76 \times n_{mech}^* - 20 \times n_{mech} \times \frac{(1-(\eta_{he} \times F_{inuse,he}))}{(1-(N_s \times 0.075))} \qquad 5$$

Repeat 2, 3, 4 and 5 a further 18 times then 2, 3 and 4 one final time.

The air throughput, in dwelling volumes per hour (a/h), is the 20th calculation of n_{mech}^* in equation 4.

The in-use factor heat exchanger efficiency is 0.85 for ductwork totally inside the heated envelope of the dwelling or if any is outside, it is insulated. It is 0.70 for if it contains any uninsulated duct work outside the heated envelope.

Appendix B Mean internal temperature tables

Table B1 SAP Mean Internal Temperature for 16 hours/day heating
SAP 2005 Table 9 - Mean internal temperature

Heating 0700-2300 each day (16 hours)
(weekend pattern)

| HLP | Heating type / responsiveness | | | | |
| | (1) | (2) | (3) | (4) | (5) |
	1.0	0.75	0.5	0.25	0.0
1.0	19.63	19.92	20.20	20.49	20.78
1.5	19.63	19.91	20.20	20.48	20.77
2.0	19.61	19.90	20.19	20.47	20.76
2.5	19.58	19.88	20.17	20.46	20.75
3.0	19.53	19.83	20.13	20.43	20.73
3.5	19.45	19.77	20.08	20.40	20.72
4.0	19.36	19.70	20.03	20.37	20.70
4.5	19.27	19.62	19.98	20.33	20.69
5.0	19.16	19.54	19.91	20.29	20.67
5.5	19.04	19.44	19.85	20.25	20.65
6.0	18.93	19.35	19.78	20.20	20.63

Table B1 SAP Mean Internal Temperature for 9 hours/day heating
SAP 2005 Table 9 - Mean internal temperature

Heating 0700-0900 and 1600-2300 each day (9 hours)
(weekday pattern)

| HLP | Heating type / responsiveness | | | | |
| | (1) | (2) | (3) | (4) | (5) |
	1.0	0.75	0.5	0.25	0.0
1.0	18.58	19.09	19.59	20.10	20.61
1.5	18.58	19.08	19.58	20.09	20.59
2.0	18.55	19.06	19.56	20.07	20.57
2.5	18.50	19.01	19.53	20.04	20.55
3.0	18.40	18.93	19.46	20.00	20.53
3.5	18.26	18.82	19.38	19.94	20.50
4.0	18.11	18.70	19.29	19.89	20.48
4.5	17.94	18.57	19.19	19.82	20.45
5.0	17.75	18.42	19.08	19.75	20.41
5.5	17.54	18.25	18.96	19.67	20.37
6.0	17.32	18.07	18.83	19.58	20.33

Appendix C Primary heating fraction and days of extra heating.

C1 Plant heating fraction

The fraction of the primary heating is that supplied by the heat pump dataset term plant heating fraction and is calculated as detailed below. It replaces the EN15316 calculation to provide consistency with other package types, for example, micro-cogeneration and because the method in EN15316 in applies to 24 hour heating only. The primary heating fraction also depends on the plant size ratio.

Calculate the appropriate base temperature to calculate T_{oL} according to (8) and using the climate temperature calculate $DD(T_b)$, $\left[dd(T_b)\right]_{T_{oL}}^{T_{oW}}$ and $\left[N(T_o)\right]_{T_{oC}}^{T_{oL}}$ to calculate the primary fraction and hence the plant fraction as a function of the *PSR* according to (9) or (10) using the values tabulated below.

Table C1 Data required to calculate the primary heating fraction

Description	Symbol	Value
Base temperature (24 hr/day)	T_b	13.78 °C
Base temperature (16 hr/day)	T_b	12.68°C
Base temperature (77 hr/week)	T_b	11.99°C
Design outside temperature	T_{od}	-5°C
Inside temperature	T_{od}	19.2°C
Hours of heating per day	h	11[*], 16 or 24
Lowest external temperature that the plant satisfy when operating at full load	T_{oL}	See (8)
Plant size ratio	*PSR*	
Number of degree-days to base temperature	$DD(T_b)$	From climate data
Number of days when the external temperature is below lowest temperature that the plant can satisfy	$\left[N(T_o)\right]_{T_o=T_{oC}}^{T_o=T_{oL}}$	From climate data
Number of degree-days when the external temperature is below lowest temperature that the plant can satisfy	$\left[dd(T_b)\right]_{T_o=T_{oC}}^{T_o=T_{oL}}$	From climate data
Primary heating fraction	$f_{sp,np}$	See (9) or (10)
Plant heating fraction	f_{pl}	

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[*] This actually 9 hours in week and 16 at weekends which averages out at 11 per week.

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

The number of hours the plant operates for extended hours is given in Table C2.

Table C2 Days of extended heating

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

The division of N_{days} = 234 was introduced as this is the heating over 8 whole months whilst SAP defined the heating season to the nearest in whole weeks (34 weeks has 238 days, 170 weekdays and 68 weekends).

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

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

C2 Derivation of plant heating fraction

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

$$DD(T_b) \times 0.024 \times Q_{loss} \qquad\qquad 1$$

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

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

$$\left[Q_{sp}\right]_{T_o} = \left[dd(T_b)\right]_{T_o} \times 0.024 \times Q_{loss} \qquad\qquad 2$$

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

From the definition of design heat loss:

$$dhl(kW) = (T_{id} - T_{od}) \times Q_{loss}(W/^\circ C) \div 1000 \qquad\qquad 3$$

Using (1) and (2) to eliminating Q_{loss} gives:

$$\left[Q_{sp}\right]_{T_o} = \left[dd(T_b)\right]_{T_o} \times 24 \times dhl(kW)/(T_{id} - T_{od}) \qquad\qquad 4$$

And using the definition of plant size ratio (the capacity at design temperatures divided by the design heat loss: Q_{nom}/dhl) to eliminate the design heat loss in (4) then:

$$\left[Q_{sp}\right]_{T_o} = \left[dd(T_b)\right]_{T_o} \times \frac{24 \times Q_{nom}}{PSR \times (T_{id} - T_{od})} \qquad\qquad 5$$

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

$$h \times Q_{nom} = \left[dd(T_b)\right]_{T_{oL}} \times \frac{24 \times Q_{nom}}{PSR \times (T_{id} - T_{od})} \qquad\qquad 6$$

Rearranging gives:

$$\left[dd(T_b)\right]_{T_{oL}} = h \times PSR \times (T_{id} - T_{od})/24 \qquad\qquad 7$$

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

$$T_{oL} = T_b - h \times PSR \times (T_{id} - T_{od})/24 \qquad\qquad 8$$

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

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

$$f_{pl} = \frac{\left[dd(T_{b,h})\right]_{T_o=T_{oL}}^{T_o=T_b} + (T_b - T_{oL}) \times \left[N(T_o)\right]_{T_o=T_{oC}}^{T_o=T_{oL}}}{DD(T_b)} \qquad\qquad 9$$

$DD(T_b)$ is the usual degree-days over the heating season $dd(T_b)$ is the degree-days summed between the warmest and the day when the plant just meets the required demand and $N(T_o)$ number of days between the days when the plant can not met the demand (T_{oC} is the coldest temperature in the heating season).

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

$$f_{pl} = \{\left[dd(T_{b,11})\right]_{T_o=T_{oL11}}^{T_o=T_b} + \left[dd(T_{b,16})\right]_{T_o=T_{oL16}}^{T_o=T_{oL11}}$$
$$+ \left[dd(T_{b,L24})\right]_{T_o=T_{oL24}}^{T_o=T_{oL16}} + (T_{b,24} - T_{oL24}) \times \left[N(T_o)\right]_{T_o=T_{oC}}^{T_o=T_{oL24}} \} \div \qquad 10$$
$$\{\left[dd(T_{b,11})\right]_{T_o=T_{oL11}}^{T_o=T_b} + \left[dd(T_{b,16})\right]_{T_o=T_{oL16}}^{T_o=T_{oL11}} + \left[dd(T_{b,L24})\right]_{T_o=T_{oC}}^{T_o=T_{oL16}} \}$$

The subscripts L11, L16 and L24 indicate the external temperature conditions as calculated in (8) for 11, 16 and 24 hours/day heating. (T_{oC} is the lowest temperature in the climate record over the thirty year period 1979-2008).

Table C3 Days at longer heating duration

Weekday/weekend heating hours	Number of days operating at the number of hours indicated by the subscript instead of the SAP standard hours indicated by the second subscript		
	$N_{16,9}$	$N_{24,9}$	$N_{24,16}$
24/24	0	170	68
16/16	170	68	0
11/16	0	0	0
Varies	see table C4	see table C4	see table C4

Table C4 Look-up table for heating fraction and extra days at longer heating duration

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