Method to evaluate the annual energy performance of micro-cogeneration heating systems in dwellings

prepared for Defra CEEH by
John Hayton and Bruce Young, BRE

9 October 2008

CONTENTS

Method to evaluate the annual energy performance of micro-cogeneration heating systems in dwellings

INTRODUCTION

Micro-cogeneration, also known as micro-CHP, is the process of heating water and generating electricity simultaneously, on a sufficiently small scale to suit a single dwelling. Within this document the term is abbreviated to “µ-cogen”. A µ-cogen “unit” is a combined engine and generator (or perhaps a fuel cell), and a µ-cogen “package” is the unit together with other components comprising a complete working system.

µ-cogen is distinguished from large plant cogeneration not by size alone but by type of usage. This paper presents a method for determining the annual energy performance of µ-cogen in single dwellings in the UK, making specific assumptions about the size and the way it is used, but not about the design or particular technology adopted. The method requires input data obtained from suitable laboratory tests carried out under carefully controlled conditions, which have been specified in a Publicly Available Specification PAS 67 (see Ref. [2]). Within this document the laboratory test conditions are frequently referred to as “PAS 67”.

There are two outputs from the annual energy performance method: (i) a set of technical parameters for use in SAP 2005, known as the “intermediate results”, and (ii) a seasonal performance index, intended to express heating and generating performance over a whole year as a single number, to be known as the Heating Plant Emission Rate (HPER). SAP (see Ref. [1]) is the UK Government’s Standard Assessment Procedure for Energy Rating of Dwellings, and is used to demonstrate compliance with Building Regulations. Derivation of the HPER from laboratory tests is a process conceptually similar to SEDBUK for boilers (see Ref. [10]), also derived from standard laboratory tests. However, no direct comparison can be drawn between the HPER (measured in kgCO_2/kWh) and SEDBUK (a thermal efficiency): this is because the test conditions for µ-cogen and boilers are entirely different, and because the HPER takes into account how the heating plant is matched to the building.

The remainder of the paper is divided into three main parts to explain the principles on which the method is based, the calculation procedure to be followed, and the theoretical background to justify the procedure.

Part 1 : PRINCIPLES

1.1 Scope

This paper defines a method of calculation to express the annual average energy performance of µ-cogen packages installed for space heating and hot water service in dwellings in the UK. The package is assumed to be the primary heating system within the dwelling; ie, called upon first to meet demands for heating and hot water service. Estimates of annual energy consumption and carbon emissions are calculated under standardised conditions of heating and hot water demand, and thus provide a means of comparing the performance of different systems under the same conditions.

This approach complies with the “annual load profile” method set out in section 5.7 of the European standard EN15136-4-4 (Ref. [9]). It is well suited to µ-cogen installations that supply all or most of the heat demand for the building and may be regarded as a substitute for a boiler. It relies upon data obtained for a number of part-load conditions, measured under prescribed laboratory conditions, together with a heat load profile (the number of days per year on which the package is expected to meet each specified part-load heat demand range). The test data is combined with the heat load profile to calculate the annual fuel consumed and electricity generated. The laboratory tests are the prime determinant of the seasonal performance index, and the accuracy of the tests is propagated to those obtained from the annual method.

Operation of the µ-cogen package is assumed to be governed by heating requirements alone, and full credit is given for electricity generated on the presumption that it displaces an equivalent amount that would otherwise have been generated for the public electricity supply. The annual method takes into account any auxiliary heating needed when the µ-cogen package cannot meet the full heating and hot water requirements of the dwelling, and allows for the additional consumption to achieve design temperatures when it is necessary to extend the hours of heating beyond the times prescribed in SAP (Ref. [1]).

The results are a set of values (the “intermediate results”) for use in energy modelling and energy rating schemes such as SAP. They are defined here and in Appendix N of SAP 2005. Since April 2006 there has been provision in the Boiler Efficiency Database (Ref. [10]) for a table of µ-cogen intermediate results, so that they may be downloaded to SAP programs automatically.

A separate calculation performed upon the intermediate results gives a single performance index to assist comparison of different products. The index is expressed in units of carbon dioxide emitted per unit of useful heat delivered, allowing for the benefit of electricity generated. A carbon index was chosen as this was the preferred option from the 6 presented at the April 2004 consultation, and it also corresponds to measures chosen for the April 2006 revision of Part L of the Building Regulations.

1.2 Fundamental assumptions

The annual method requires results obtained from laboratory tests carried out under various part-loading conditions, and depends on fundamental assumptions about usage and operation as described below. Part-load is expressed as the percentage of the daily heat output from the µ-cogen package when running at nominal rated heat output (ie, 100% is 24 hours times the nominal rated heat output).

The method is valid only in the following circumstances:

1. Laboratory tests have been carried out under prescribed conditions (see Ref. [2]). The tests must have been carried out while the package was operating in synchronous mode (not island mode) – see 4 below.
2. Heat output is confined to domestic heating and hot water service in typical UK dwellings.
3. The µ-cogen package is the primary heating system for the dwelling and is heat-led; ie, it operates only when there is a demand for space heating or water heating, and heat is never wasted.
4. Electricity generated is a useful by-product, irrespective of the demand within the building, and is never wasted. The full amount of electricity generated is given carbon emission credit on the presumption that it displaces an equivalent amount that would otherwise be generated by the public electricity supply. Therefore the method applies only to µ-cogen systems that are connected to the public supply and are capable of exporting electrical power to it.
5. The µ-cogen package is matched to the building, using a suitable plant size ratio. Some over- or under-sizing is tolerable, and is accounted within the method by adjustment of the load profile. If under-sized, the shortfall in delivery of space heating and hot water is assumed to be met by direct acting electrical heating, unless within a particular SAP assessment a different type of secondary heating system has been identified. If over-sized, the load profile is adjusted accordingly.
6. The µ-cogen system is used either to provide space heating and hot water service, or to provide space heating alone. If hot water service is included then it is assumed to be provided by the µ-cogen package throughout the year. If hot water service is not included, then it is assumed to be provided by an electrical immersion heater for the seasonal performance index, or by the specified hot water source in a SAP assessment.
7. Current limitations of the method are:
    - (i) the heating season and summer season are assumed fixed length (see ¶3.2);
    - (ii) during the heating season the hot water load is added to the space heating load and treated indistinguishably;
    - (iii) for the purpose of calculating a seasonal performance index, the hot water demand is taken to be the UK national average for dwellings (see ¶3.3);
    - (iv) the heating circulator if not included in the electricity data has an annual power requirements as specified in SAP;
    - (v) the µ-cogen package has been tested in ‘synchronous’ mode, and any power conversion circuitry or apparatus needed to enable power export to the public electricity supply is included within the package for the purposes of all the PAS 67 tests (see ¶2.2);
    - (vi) The plant size ratio must not be less than 0.5 or greater than 4 (see ¶1.3.5 and ¶3.4).

1.3 Principles of the method

The method comprises the following parts:

1.3.1 Input data

Most of the input data are results from the laboratory test procedure (Ref. [2]), which give performance under various part-load operating conditions. Part-load operation in these circumstances means operation over the heating period of a day in which the heat generated for space heating is a specified fraction of the full heat output. The laboratory tests have been designed to produce values specifically for this purpose (they are not instantaneous measurements, as in standard boiler tests). Results from the tests will therefore take account of the effect of the internal control strategy within the µ-cogen package, which may exploit modulation, intermittent operation, and multi-stage heat generation in any combination.

1.3.2 Data options

Some µ-cogen packages may optimise their performance by heating the dwelling 24 hours/day or 16 hours/day, rather than in the SAP standard heating time of 77 hours per week (11 hours/day on average). Some packages may adjust the hours of heating daily, depending on the severity of the weather. Others may allow intermittent operation without restriction, as is assumed by the SAP for boilers.

To allow for these variations, the method assesses the µ-cogen package tested under any of the four regimes specified in the PAS 67 laboratory procedure:

> Regime 1 – 24 hours/day – Continuous 100%, 30%, and 10% part-load
>
> Regime 2 – 16 hours/day – Continuous 100%, plus uni-modal operation (07.00-23.00) at 30% and 10% part-load
>
> Regime 3 – 11 hours/day – Continuous 100%, plus bi-modal operation (06:00- 09:00 and 15:00-23:00) at 30% and 10% part-load
>
> Regime 4 – Mixed option – Continuous 100%, plus uni-modal operation at 30% part-load, plus bi-modal operation at 10% part-load.

1.3.3 Plant size ratio(PSR)

The plant size ratio (PSR) is defined as the nominal heat output of the heating plant divided by the design heat loss (the average heat loss of the building on a cold day with a temperature differential of 20°). For a given heat demand, the PSR determines the part-load condition for the heating plant. The design heat loss is calculated in accordance with normal practice; eg, as in BS5449 (see Ref. [3]) or its successor.

The annual results are required for four values of PSR: 0.5, 1, 1.5 and 4.

For a particular dwelling where the design heat loss is known the annual results are then interpolated using the results for the above values of PSR.

The PSR must not be lower than 0.5. If it were less than 0.5, then supplementary heating of more than half the heat demand would be required to meet the design temperature for 77 hours/week, and the µ-cogen package cannot be regarded as the primary heating system of the dwelling.

1.3.4 Fuel input and power output under part-load conditions

Daily electricity generated, heat generated and fuel consumed are measured for a limited number of part-loads. As a minimum, laboratory tests are carried out at 0% (standby), 10%, 30%, and 100% of the full-load 24-hour maximum load. To reduce the errors of interpolation and improve accuracy, tests at supplementary part load conditions 20%, 40%, 60%, 70%, 80% or 90% may also be carried out: they may be beneficial where, for example, it is desired to take account of conditions in which the ratio of electricity generated to heat produced is greatest.

All laboratory tests must have been carried out in ‘synchronous’ mode (see ¶1.2 item 7(v)).

1.3.5 Annual fuel consumption and electricity generated

Part-loading conditions in dwellings in the UK are represented by a heat load profile; the number of days per heating season at 13 part-load bands, each approximately 10% in range. For example, one range is number of days the package is expected to operate between 5% and 15% of the full load. Heat load profiles are derived from meteorological data (¶3.6) and vary with plant sized ratio and heating regime. To estimate the annual fuel input and net electricity generated for the µ-cogen package the relevant profile is multiplied by the interpolated part-load performance results.

The ranges are selected to cover all operating conditions at approximate intervals of 10%. The intervals are not exactly 10% as three narrow 1% ranges are added at the maximum load for bi-modal, uni-modal and continuous to prevent bias (¶3.15). Also to reduce bias the ranges are centred near 5%, 15%, 25% and etc to reduce bias.

It is assumed that the µ-cogen package is the primary heating system of the dwelling and is heat-led, controlled to follow variations in heating demand.

1.3.6 Extended heating factor

If the package is assessed under 24 hours/day heating, 16 hours/day, or other extended hours of heating operation, additional heat will be needed to keep the house warm outside the standard heating hours assumed by SAP. This increase is represented in two ways:

i) In the intermediate results, as the number of days the package is expected to operate for 24 and 16 hours day.

ii) In the seasonal performance index, through the introduction of an extended heating factor, X (see ¶3.10).

1.3.7 Auxiliary space and water heating requirements

The number of days, if any, on which additional space heating is required to meet the needs of the building is estimated from the heat load profile in conjunction with the plant size ratio and hours of operation (See ¶3.11). In the calculation of the seasonal performance index, it is assumed that direct acting electric heaters supply any auxiliary heating required. In the intermediate results intended for SAP, it is specified as an auxiliary heat quantity, allowing the SAP program to use an alternative secondary heating source nominated by the assessor, if there is one.

If the µ-cogen package does not provide hot water service, it is assumed that an auxiliary water heater provides the service throughout the year. In the calculation of the seasonal performance index only, that is assumed to be an electric immersion heater. For SAP purposes, the service is assumed to be provided by the source selected by the SAP assessor.

1.3.8 Auxiliary electricity

The electricity consumed by additional components of the heating system not measured in the µ-cogen laboratory tests is calculated on the basis of operating hours and typical power ratings. The procedure allows for a system circulator pump, motorised valve, room thermostat and programmer, as would be found in a conventional domestic wet central heating system.

1.3.9 Annual fuel and electricity consumption for the building

Annual quantities are calculated for the heating and hot water installation as a whole, taking account of additional energy sources to meet the auxiliary space and water heating requirements, and auxiliary electricity.

1.3.10 Data for SAP (intermediate results)

The method produces a set of results for a known plant size ratio. These are called “intermediate results” as they are produced en route to calculating the seasonal performance index, and are retained as a group of separate values so that they may undergo further processing within SAP.

During a SAP assessment, the PSR will be calculated by the SAP program. But SAP does not include the algorithms for the annual energy performance method: instead it relies on data obtained from the Boiler Efficiency Database (Ref. [10] – shortly to be expanded to include µ-cogen results). The table in the database has been designed to provide four sets of results for different plant size ratios, and SAP will then choose the most suitable set, or interpolate between two sets.

The fours sets of intermediate results in the database table have been chosen for PSRs of 0.5, 1.0, 1.5 and 4.0 (see ¶3.17 for reasoning). Each set comprises:

1. The plant size ratio
2. Annual heat generated for space heating (kWh_h / yr)
3. Annual heat generated for hot water service (kWh_h / yr)
4. Annual auxiliary space heating requirement (kWh_h / yr)
5. Heating season thermal efficiency (% gross)
6. Summer season thermal efficiency (% gross)
7. Electricity consumed during the heating season (kWh_e / yr)
8. Electricity consumed during the summer season (kWh_e / yr)
9. Number of days µ-cogen package runs for 16 hrs instead of 9 hrs
10. Number of days µ-cogen package runs for 24 hrs instead of 9 hrs
11. Number of days µ-cogen package runs for 24 hrs instead of 16 hrs

The concept of electrical generation efficiency is not used, as a fundamental assumption of the method is that operation of the µ-cogen package is heat-led and that any electricity generated is a by-product.

1.3.11 Seasonal Performance Index: the Heating Plant Emission Rate (HPER)

The purpose of a seasonal performance index is to assist comparison of different products, using a single number. Following responses to the public consultation in April 2004, during which 6 alternative seasonal performance indices were offered for consideration, an index based on overall carbon emissions has been chosen. The index is called the Heating Plant Emission Rate (HPER), and represents the carbon dioxide emissions from fuel and power needed to provide space heating and hot water service in the building under standardised conditions. Standardised conditions, while typical, are far from universal.

The HPER is defined as the carbon dioxide emissions from fuel and power consumed by the heating plant, offset by the emissions saved as a result of central electricity production avoided, divided by the heat output over the whole year. It is measured in units of kg of $C0_2$ per kWh.

It is important to remember that:

(i) the HPER includes any auxiliary space and water heating that may be necessary; i.e., it represents the performance of <u>all</u> heating plant needed to provide space and water heating service to the building;

(ii) the heat demand of the building and the heat output from the µ-cogen package are linked by the plant size ratio;

(iii) full credit is given for all electricity generated, as it is assumed that any not used within the building is exported to the grid.

Part 2 : PROCEDURE

2.1 Accuracy

For consistency and to prevent rounding errors, all calculations must be carried out to six significant figures, with intermediate results and seasonal performance index quoted to 3 significant figures.

2.2 Obtain input data

Data required is shown in Table 1. Results are required from laboratory tests carried out in accordance with the PAS 67 laboratory procedure. Results tables 2, 3 and 4 of PAS 67 are intended to hold characteristics declared by the manufacturer and results from the laboratory tests. The relevant table of PAS 67 is shown below for each item.

Notes on the items of input data in Table 1 (see results table 2 of PAS 67 unless indicated otherwise):

Item 1 : P_{nom} – The nominal heat output in kW declared by the manufacturer. The value found in the laboratory test must not be lower (see PAS 67 results table 1).

Item 5 : The test regime, defining heating demand periods for the part-load tests, under which the µ-cogen package was measured.

Items 6,7, and 8: F_{10}, F_{30}, and F_{100} – The fuel input ("Primary fuel in"), measured by gross calorific value, in kWh/day under part-loading conditions 10%, 30% and 100%. (ie, as percentage of the maximum daily load).

Items 6,7, and 8: E_{10}, E_{30}, and E_{100} –The net electrical power generated ("Electrical output (valid)") in kWh/day for thermal part-loading conditions 10%, 30% and 100%.

Items 6,7, and 8: Q_{x1}, Q_{x2}, and Q_{100} – The heat generated ("Heat output to space heating") in kWh/day for part-loading conditions 10%, 30% and 100%.

Item 9: Q_{Wa}, F_W and E_W – The heat content of the hot water drawn, fuel input and net electrical power during the DHW test, as explained in PAS 67. These results are needed only if item 3 is "YES". For a combi package with an internal water volume of 15 litres or more, the values at 2.5% space heating load are used instead, scaled by 5.845 ÷ 0.025. 5.845 kWh/day is the energy drawn-off in the EN13203:part 2, tapping schedule number 2 (see part 3.14.4).

Q_{Wa} is the heat before any adjustment due to any change in the quantity of stored heat during the DHW test.

Items 10: E_0 and F_0 – The net electrical power generated ("Electrical output (valid)") and fuel input ("Primary fuel in") (gross) in kWh/day during standby operation over a nominal test period; scaled to an equivalent 24 hour value.

PAS 67 recognises the difficulty that 24 hours divided by the firing cycle, the time between two successive firing periods, may not be a

	whole number leading to possible large fluctuations in recorded heat and power simply because the selected 24-hours just misses or includes the next firing cycle. To over this difficulty, PAS 67 defines the nominal test period as an exact number of firing cycles and scales the heat and power accordingly.
	Pas 67 Results table 2 (standby loss row) contains the scaled values alone and PAS 67 results table 4 contains the data recorded over the nominal test period and the scaled values.
	Electrical quantities may be negative, indicating that the package has consumed more electrical power than it generated.
Item 11	These are the laboratory results from one or more optional supplementary tests at nominal part loads of 20%, 40%, 50%, 60%, 70%, 80% or 90%.
Item 12:	Island or grid (“synchronous”) mode. Only results from tests carried out in grid mode are allowable in the annual performance method.
Item 13:	Is required for regular packages only and is estimated from temperature measurements of the cylinder during the calibration and DHW test (see results table 4 of PAS67)
Item 14:	Is required for regular packages only and is estimated from temperature measurements of the cylinder (see results table 4 of PAS67).

Table 1: Input data from laboratory tests and manufacturer's declaration

Item	*PAS 67 Results table*	Description	Value		
1	*1*	Nominal rated heat output	P_{nom}: …..kW		
2	*1*	Fuel	Natural gas / LPG / oil / solid fuel		
3	*2*	DHW service	YES (package type RegPK or CombiPK) / NO (package type HeatPK)		
4	*2*	Direct DHW supply	YES (package type CombiPK) / NO (package type RegPK or HeatPK)		
5	*2*	Test regime number	Regime 1, 2, 3 or 4		
6	*2*	100% thermal output ("Full output")	Fuel input (gross) kWh/24h F_{100} =	Electrical output kWh/24h E_{100} =	Heat output kWh/24h Q_{100} =
7	*2*	30% thermal output	Fuel input (gross) kWh/24h F_{x2} =	Electrical output kWh/24h E_{x2} =	Heat output kWh/24h Q_{x2} =
8	*2*	10% thermal output	Fuel input (gross) kWh/24h F_{x1} =	Electrical output kWh/24h E_{x1} =	Heat output kWh/24h Q_{x1} =
9	*2*	DHW performance	Fuel input (gross) kWh/24h F_W =	Electrical output kWh/24h E_W =	Heat output kWh/24h Q_{Wa} =
10	*2, 4*	Standby performance	Fuel input (gross) kWh/24h F_0 =	Electrical output kWh/24h E_0 =	Heat output kWh/24h $Q_0 = 0$
11	*2*	Supplementary tests at part load s_i and condition j: where j=c for continuous, j=u for unimodal or j=b for bimodal.	Fuel input (gross) kWh/24h $F_{s_i,j}....F_{s_{n,j}}$	Electrical output kWh/24h $E_{s_i,j}....E_{s_{n,j}}$	Heat output kWh/24h $Q_{s_i,j}....Q_{s_{n,j}}$
12	*2*	Method of electricity connection	Island or grid (connected to the public mains supply)		
13	*3*	Heat required to keep the cylinder and primary pipes warm during the DHW test	Q_{hwstby} (kWh/day)		
14	*3*	Change in the energy of the water in the cylinder during the DHW test	Q_{hwres} (kWh/day)		

2.3 Preliminary calculations

The basic energy units used in PAS 67 are MJ. The annual performance method requires energy data in kWh. Convert to kWh by dividing the amounts in MJ by 3.6

For the nominal 10% and 30% thermal loads, calculate the precise part loads, $x1$ and , $x2$ as follows.

$$x1 = 100 \times \frac{Q_{x1}}{Q_{100}} \qquad x2 = 100 \times \frac{Q_{x2}}{Q_{100}}$$

For each supplementary test, if any, calculate the part load:

$$x_{s_{i,j}} = 100 \times \frac{Q_{s_i,j}}{Q_{100}}$$

where $s_{i,j}$ is the supplementary test at part load *i* and regime *j*

i = 20%, 40%, 50%, 60%, 70%, 80% or 90

j = c for continuous, u = unimodal or b = bimodal.

For the DHW test (regular packages only) adjust the heat quantity of the hot water drawn-off by:

$$Q_W (kWh) = Q_{Wa} (kWh) + Q_{hwres} (kWh)$$

2.4 Fuel input and power generated under part-load conditions

2.4.1 24 hours/day heating (100%, 30% and 10% continuous)

This section applies to the 24-hour heating assessment only -PAS 67 Table 2, Regime 1.

For each row of Table 2 below, calculate the fuel input (F3) and net electrical output (E3) by:

1) Determine the next nearest part load below and above part load, from data at the precise loads of 0%, x1%, x2%, 100% or any supplementary part load used.
2) Enter the part-load below and above x% in column B and C, and the corresponding fuel used and net electricity generated in columns E1 and E2 and F1 and F2 respectively. They differ for each row.
3) Calculate column E3 and F3 and using:

$$\text{Col F3}=\{(\text{Col D}-1)\times\text{Col F1}\}+(\text{Col D}\times\text{F2})$$

$$\text{Col E3}=\{(\text{Col D}-1)\times\text{Col E1}\}+(\text{Col D}\times\text{E2})$$

Table 2: Fuel input and power output 24 hours/day heating worksheet

Part load (%)				Net electrical power output (kWh/day)			Gross fuel input (kWh/day)		
A	B	C	D	E1	E2	E3	F1	F2	F3
x	Nearest value		$\frac{(x-x_L)}{(x_U-x_L)}$	at x_U	at x_L	at x	at x_U	at x_L	at x
	above x x_U	below x x_L							
2.5%	x1	0		E_0	E_{x1}		F_0	F_{x1}	
10.0%									
20.0%									
30.0%									
40.0%									
45.5%									
51.0%									
61.0%									
66.5%									
72.5%									
83.0%									
94.0%									
100%	n/n	n/n	n/n	n/n	n/n	E_{100}	n/n	n/n	F_{100}

n/n – not necesessary

2.4.2 16 hours/day heating (100% continuous, 30% unimodal, 10% unimodal)

This section applies to the 16-hour heating assessment only - PAS 67 Table 2, Regime 2.

Estimate the fuel input and net electricity generated when running at full output for 16 hours:

$F_{66.5\%} = {}^{16}/_{24} \times F_{100} + {}^{8}/_{24} F_{0}$ $E_{66.5\%} = {}^{16}/_{24} \times E_{100} + {}^{8}/_{24} E_{0}$

For each row of table 3 below, calculate the fuel input and net electrical output:

1) Determine the nearest part load below and above part load, x, from 0%, x1%, x2%, 66.5%, or any supplementary part load used. Enter the part-load below and above in column B and C. They differ for each row.
2) Enter the part-load below and above x% in column B and C, and the corresponding fuel used and net electricity generated in columns E1 and E2 and F1 and F2 respectively. They differ for each row.
3) Calculate column E3 and F3 and using:

$$\text{Col F3}=\{(\text{Col D-1})\times\text{Col F1}\}+(\text{Col D}\times\text{F2})$$

$$\text{Col E3}=\{(\text{Col D-1})\times\text{Col E1}\}+(\text{Col D}\times\text{E2})$$

Table 3: Fuel input and power output 16 hours/day heating worksheet

Part load (%)				Net electrical power output (kWh/day)			Gross fuel input (kWh/day)		
A	B	C	D	E1	E2	E3	F1	F2	F3
x	Nearest value above x x_U	Below x x_L	$\frac{(x - x_L)}{(x_U - x_L)}$	at x_U	at x_L	at x	at x_U	at x_L	at x
2.5%	x1	0		E_0	E_{x1}		F_0	F_{x1}	
10.0%									
20.0%									
30.0%									
40.0%									
45.5%									
51.0%									
61.0%									
66.5%	n/n	n/n	n/n	n/n	n/n	$E_{66.5}$	n/n	n/n	$F_{66.5}$
72.5%	n/n	n/n	n/n	n/n	n/n	0	n/n	n/n	0
83.0%	n/n	n/n	n/n	n/n	n/n	0	n/n	n/n	0
94.0%	n/n	n/n	n/n	n/n	n/n	0	n/n	n/n	0
100%	n/n	n/n	n/n	n/n	n/n	0	n/n	n/n	0

n/n means not necessary. Loads above 66.5% of the maximum daily output are assigned zero as they are impossible under 16-hour operation, requiring more than 16 hours.

2.4.3 11 hours/day heating (100% continuous, 30% bimodal, 10% bimodal)

This section applies to the 11-hour heating assessment only - PAS 67 Table 2, Regime 3.

Estimate the fuel input and net electricity generated when running at full output for 11 hours:

$$F_{45.5} = {}^{11}/_{24} \text{ x } F_{100} + {}^{13}/_{24} F_0 \qquad E_{45.5} = {}^{11}/_{24} \text{ x } E_{100} + {}^{13}/_{24} E_0$$

For each row of table 4 undertake the linear interpolation of the fuel input and net electrical output from:

1) Determine the nearest part load below and above part load, x, from 0%, x1%, x2%, 45.5%, or any supplementary part load used. Enter the part-load below and above x% in column B and C. They differ for each row.
2) Enter the part-load below and above x% in column B and C, and the corresponding fuel used and net electricity generated in columns E1 and E2 and F1 and F2 respectively. They differ for each row.
3) Calculate column E3 and F3 and using:

$$\text{Col F3} = \{(\text{Col D} - 1) \times \text{Col F1}\} + (\text{Col D} \times \text{F2})$$

$$\text{Col E3} = \{(\text{Col D} - 1) \times \text{Col E1}\} + (\text{Col D} \times \text{E2})$$

Table 4: Fuel input and power output at part-load conditions – 11 hours/day heating

Part load (%)				Net electrical power output (kWh/day)			Gross fuel input (kWh/day)		
A	B	C	D	E1	E2	E3	F1	F2	F3
x	Nearest value		$\frac{(x - x_L)}{(x_U - x_L)}$	at x_U	at x_L	at x	at x_U	at x_L	at x
	above x x_U	below x x_L							
2.5%	x1	0		E_0	E_{x1}		F_0	F_{x1}	
10.0%									
20.0%									
30.0%									
40.0%									
45.5%						$E_{45.5}$			$F_{45.5}$
51.0%	n/n	n/n	n/n	n/n	n/n	0	n/n	n/n	0
61.0%	n/n	n/n	n/n	n/n	n/n	0	n/n	n/n	0
66.5%	n/n	n/n	n/n	n/n	n/n	0	n/n	n/n	0
72.5%	n/n	n/n	n/n	n/n	n/n	0	n/n	n/n	0
83.0%	n/n	n/n	n/n	n/n	n/n	0	n/n	n/n	0
94.0%	n/n	n/n	n/n	n/n	n/n	0	n/n	n/n	0
100%	n/n	n/n	n/n	n/n	n/n	0	n/n	n/n	0

n/n means not necessary. Loads above 45.5% of the maximum daily output are assigned zero as they are impossible under 11-hour operation more than 11 hours of would be required.

2.4.4 Mixed heating regime (100% continuous, 30% unimodal 10% bimodal)

This section applies to the mixed heating assessment only - PAS 67 Table 2, Regime 4. Care must be taken to ensure linear interpolation is only carried out using a pair of values for the same mode of operation.

Calculate the fuel consumed and electricity generated at the maximum load of the unimodal and bimodal operation:

$F_{45.5} = {}^{11}/_{24} \times F_{100} + {}^{13}/_{24} F_0$ $\quad E_{45.5} = {}^{11}/_{24} \times E_{100} + {}^{13}/_{24} E_0$

$F_{66.5} = {}^{16}/_{24} \times F_{100} + {}^{8}/_{24} F_0$ $\quad E_{66.5} = {}^{16}/_{24} \times E_{100} + {}^{8}/_{24} E_0$

Estimate the fuel consumed and electricity generated thus

$F_{x2,c} = F_{x2,u} - (8/16 \times F_0)$

$E_{x2,c} = F_{x2,u} - (8/16 \times E_0)$

Calculate by linear interpolation of the fuel used and electricity generated in table 5 by:

1) For the rows with loads less than or equal to 45.5%, determine the nearest part load below and above part load, x, from 0%, x1%, or 45.5%. Note the nominal test load (x2%) at 30% is excluded from the list because it measured under unimodal operation. Enter the part-load below and above x% in column B and C, and the corresponding fuel used and net electricity generated in columns E1 and E2 and F1 and F2 respectively. They differ for each row.
2) For unimodal rows (loads between 51% and 66.5%) determine the nearest part load below and above part load, determine the nearest part load below and above part load, x, from x2%, 66.5% 100% or any supplementary part load (x_{si}). Enter the part-load below and above x% in column B and C, and the corresponding fuel used and net electricity generated in columns E1 and E2 and F1 and F2 respectively. They differ for each row.
3) For continuous rows (loads above 66.5%) determine the nearest part load below and above part load, determine the nearest part load below and above part load, x, from x2, 100% or any supplementary part load (x_{si}). Enter the part-load below and above x% in column B and C, and the corresponding fuel used and net electricity generated in columns E1 and E2 and F1 and F2 respectively. They differ for each row.
4) Calculate column E3 and F3 and using:

$$\text{Col F3} = \{(\text{Col D}-1) \times \text{Col F1}\} + (\text{Col D} \times \text{F2})$$

$$\text{Col E3} = \{(\text{Col D}-1) \times \text{Col E1}\} + (\text{Col D} \times \text{E2})$$

Table 5: Fuel input and power output at part-load conditions – mixed heating

Part load (%)				Net electrical power output (kWh/day)			Gross fuel input (kWh/day)		
A	B	C	D	E1	E2	E3	F1	F2	F3
x	Nearest value		$\frac{(x - x_L)}{(x_U - x_L)}$	at x_U	at x_L	at x	at x_U	at x_L	at x
	above x x_U	below x x_L							
2.5%	x1	0		E_0	E_{x1}		F_0	F_{x1}	
10.0%									
20.0%									
30.0%									
40.0%									
45.5%	n/n	n/n	n/n	n/n	n/n	$E_{45.5}$	n/n	n/n	$F_{45.5}$
51.0%									
61.0%									
66.5%	n/n	n/n	n/n	n/n	n/n	$E_{66.5}$	n/n	n/n	$F_{66.5}$
72.5%									
83.0%									
94.0%									
100%	n/n	n/n	n/n	n/n	n/n	E_{100}	n/n	n/n	F_{100}

(n/n means not necessary).

2.5 Plant size ratio

From this point onwards, four sets of calculation are required each based on a “plant size ratio” of *R* = 0.5, 1, 1,5 and 4.

R may be calculated for a particular building where the design heat loss is known. The annual results at this known *R* are interpolated using the results at the four R values.

Do not perform the calculations using the known *R* value.

If required calculate the plant size ratio as:

$$R = \frac{P_{nom}}{dhl}$$

with *dhl* is the design heat loss (in kW) of the dwelling when the design temperature differential between inside and outside is 20°C and

P_{nom} is the nominal heat output in kW.

The method is invalid if the known *R* is outside the range 0.5 to 4.

2.6 Fuel consumed and electricity generated summation

Copy the values for the fuel input and electrical output calculated in columns F3 and E3 of table 2, table 3, table 4 or table 5 into table 6 below.

Select table A1, A2, A3 or A4 in Appendix A according to test regime. For the value of *R*, select the load profile (a column holding numbers of days) from the table and copy it into column D of the worksheet below Table 6. Calculate the totals F_T and E_T by completing the worksheet. A separate table is required for each four values of R.

An explanation of load profiles is given in ¶3.6.

Table 6: Worksheet for fuel used and electricity generated due to space heating

Column A	Column B	Column C	Column D	= B x D	= C x D
Part-load	Fuel input (gross) (kWh/day)	Net electrical output (kWh/day)	Number of days at part load	Total fuel used (gross) (kWh)	Total net electricity generated (kWh)
2.5%					
10.0%					
20.0%					
30.0%					
40.0%					
45.5%					
51.0%					
61.0%					
66.5%					
72.5%					
83.0%					
94.0%					
100.0%					
TOTALS:			243	F_T =	E_T =

2.7 Auxiliary space heating requirement

Locate the number of load hours N_{h1} and N_{h2} from one of table A1 to A4 in Appendix A according to test regime 1, 2, 3 or 4. Calculate the auxiliary heating requirement for space heating, $Heat_{aux}$, in kWh per year as:

$$Heat_{aux} = \left(N_{h2} - N_{h1}\right) \times \frac{Q_{100}}{24}$$

¶3.11 explains the information underlying the calculation.

2.8 Auxiliary water heating requirement

Determine any auxiliary heat requirement for the hot water service.

(i) If the package provides domestic hot water (DHW) for the whole year:

$$HW_{aux} = 0$$

(ii) If the package does not provide hot water service:

$$HW_{aux} = 2961$$

See ¶3.3 for derivation.

2.9 Auxiliary electricity

If the electricity generated is offset by internal water circulator, set the typical power consumption in kWh/yr of the circulator to:

$$Elec_{aux} = 0 \text{ (see ¶3.13)}$$

If the electricity generated is not off-set by the internal circulator, or no internal circulator present, set the typical power consumption in kWh/yr of the circulator to:

$$Elec_{aux} = 130 \text{ (see ¶3.13)}$$

2.10 Fuel and electricity during the summer season

(i) If the package provides domestic hot water service for the whole year:

$$Fuel_{sum} = 113 \times F_W$$

$$Elec_{sum} = 113 \times E_W$$

$$Heat_{sum} = 113 \times Q_W$$

For an explanation see ¶3.12.

(ii) If the package does not provide hot water service throughout the year

$$Fuel_{sum} = 0$$

$$Elec_{sum} = 0$$

$$Heat_{sum} = 0$$

2.11 Fuel and electricity in the heating season

Set the heat generated in the heating season and standby heat loss by any hot water service provided as follows:

(i) If DHW is provided all the year round by a regular package (see Table 1, item 3):

$$Heat_{hs,hw} = 225 \times Q_w$$

$$Heat_{hwstbylab} = 365 \times Q_{hwstbylab}$$

(ii) If DHW is provided all the year round by a combi package (see Table 1, item 3):

$$Heat_{hs,hw} = 225 \times Q_w$$

$$Heat_{hwstbylab} = 0$$

(iii) If DHW is not provided all the year round (see Table 1, item 3)::

$$Heat_{hs,hw} = 0$$

$$Heat_{hwstbylab} = 0$$

Locate the number of load hours N_{h1} from one of Tables A1 to A4 in Appendix A and calculate fuel consumption and net electricity generated in the heating season as follows:

$$Fuel_{hs} = F_T \times \left(1 + \frac{Heat_{hs,hw} + 0.67 \times Heat_{hwstbylab}}{(Q_{100} / 24) \times N_{h1}} \right)$$

$$Elec_{hs} = E_T \times \left(1 + \frac{Heat_{hs,hw} + 0.67 \times Heat_{hwstbylab}}{(Q_{100} / 24) \times N_{h1}} \right)$$

See ¶3.12 for an explanation.

2.12 Annual results

If only calculating results for use in the SAP skip ¶2.12 and proceed to ¶2.13.

If the design heat loss was specified as a range (see ¶2.5(ii)), firstly calculate two sets of in-between results for each item below and secondly calculate the arithmetic mean (harmonic mean for annual heat generated in ¶2.12.3) of the in-between results. Use the mean for the calculations as explained in ¶2.14.

2.12.1 Annual fuel consumed

Calculate the annual fuel consumed, in kWh/yr, as:

$$Fuel_{con} = Fuel_{hs} + Fuel_{sum}$$

2.12.2 Annual electricity consumed

Calculate the electricity consumed, in kWh/yr, as:

$$Elec_{conHP} = -Elec_{hs} - Elec_{sum} + HW_{aux} + Heat_{aux} + Elec_{aux}$$

2.12.3 Annual heat generated for HPER purposes

Locate the heat generated in the heating season due to a domestic hot water service, if any, $Heat_{hs,hw}$ (¶2.11) and in the summer season $Heat_{sum}$ (¶2.10), the number of full load hours N_{h1} from one of Tables A1 to Table A4, the heat generated for the100% continuous load test Q_{100}, any auxiliary electricity for water heating HW_{aux} (¶2.8) or space heating $Heat_{aux}$ (¶2.9) to calculate the annual heat generated for the denominator of the HPER equation only:

$$Heat_{genHP} = \frac{Q_{100}}{24} N_{h1} + Heat_{hs,hw} + Heat_{sum} + HW_{aux} + Heat_{aux}$$

(See ¶3.14.1 and ¶3.14.3 for reasoning)

2.13 Intermediate results

Annual energy performance is represented by quantities called 'the intermediate results', which are intended for use in energy modelling and energy rating procedures such as SAP. Although they are a requirement for SAP, this section may be omitted when calculating a seasonal performance index value only.

SAP assessments normally rely on data extracted from the Boiler Efficiency Database (see Ref. [10]), which has provision for µ-cogen products. Four sets of µ-cogen intermediate results, based on plant size ratios 0.5, 1.0, 1.5 and 4.0, are needed for entries in the Boiler Efficiency Database.

2.13.1 Annual heat generated for space heating

Calculate the annual heat generated for space heating from:

Locate the number of full load hours N_{h1} from one of table A1 to A4 in Appendix A according to test regime 1, 2 3 or 4. Calculate the auxiliary heating requirement for space heating, $Heat_{sp}$, in kWh per year as follows:

$$Heat_{sp} = N_{h1} \times \frac{Q_{100}}{24}$$

2.13.2 Annual heat generated for DHW

Calculate the heat generated in the summer season and heating season due to the hot water production using $Heat_{sum}$ (¶2.10), $Heat_{hs,hw}$ (¶2.11) and $Heat_{hwstbylab}$ (¶2.11) by:

$$Heat_{DHW} = Heat_{sum} + Heat_{hs,hw} + Heat_{hwstbylab}$$

2.13.3 Annual auxiliary heating

Note $Heat_{aux}$, the auxiliary heat required for space heating, as calculated in ¶2.7.

2.13.4 Thermal efficiency (heating season)

Locate the heat generated during the heating season due to hot water production (¶2.13.1), the fuel consumed during the heating season $Fuel_{hs}$ (¶2.11) and $Heat_{hs,hw}$ (¶2.11) and $Heat_{hwstbylab}$ (¶2.11) to calculate thermal efficiency in the heating season as:

$$\eta_{thermal,hs} = \frac{(Heat_{sp} + Heat_{hs,hw} + \{0.67 \times Heat_{hwstbylab}\})}{Fuel_{hs}}$$

2.13.5 Thermal efficiency (summer season)

If DHW is provided all the year round, locate the fuel consumed (¶2.10) and heat generated during the summer (¶2.10) and calculate thermal efficiency in the summer season as:

$$\eta_{thermal,sum} = \frac{Heat_{sum} + \{0.33 \times Heat_{hwstbylab}\}}{Fuel_{sum}}$$

If DHW is not provided, set the thermal efficiency to a null value, as it is undefined and not needed.

2.13.6 Electricity consumed (heating season)

Calculate the electricity consumed during the heating season, using the electricity generated from ¶2.11, as:

$$Elec_{conSAP,hs} = -Elec_{hs}$$

2.13.7 Electricity consumed (summer season)

Calculate the electricity consumed during the summer season, using the electricity generated from ¶2.10, as:

$$Elec_{conSAP,sum} = -Elec_{sum}$$

2.13.8 Days operating at 16 hours instead of 9 hours

Note or calculate the number days that the package is expected to operate for 16 hours instead of 9 hours from Table 7, depending on *R* and test regime.

Table 7: Number of days heating is required for 16 hours instead of 9 hours, $N_{16,9}$

Assessment option	Heating hours/day in tests	Number of days
PAS 67 Table 2 Regime 1	24	None
PAS 67 Table 2 Regime 2	16	68
PAS 67 Table 2 Regime 3	11	None
PAS 67 Table 2 Regime 4	Mixed	N_u x 0.286 [1]

N_u is tabulated in table A4 Appendix A.

---

[1] This is 2/7th of the week.

2.13.9 Days operating at 24 hours instead of 9 hours

Note or calculate the number days that the package is expected to operate for 24 hours instead of 9 hours from Table 8, depending on *R* and test regime.

Table 8: Number of days heating is required for 24 hours instead of 9 hours, $N_{24,9}$

Assessment option	Heating hours/day in tests	Number of days
PAS 67 Table 2 Regime 1	24	68
PAS 67 Table 2 Regime 2	16	None
PAS 67 Table 2 Regime 3	11	None
PAS 67 Table 2 Regime 4	Mixed	N_c x 0.286 [1]

N_c is tabulated in table A4 Appendix A.

2.13.10 Days operating at 24 hours instead of 16 hours

Note or calculate the number days that the package is expected to operate for 24 hours instead of 16 hours from Table 9, depending on *R* and test regime.

Table 9: Number of days heating is required for 24 hours instead of 16 hours, $N_{24,16}$

Assessment option	Heating hours/day in tests	Heating and hot water
PAS 67 Table 2 Regime 1	24	170
PAS 67 Table 2 Regime 2	16	None
PAS 67 Table 2 Regime 3	11	None
PAS 67 Table 2 Regime 4	Mixed	N_c x 0.714 [2]

N_c is tabulated in table A4 Appendix A.

2.14 Seasonal Performance Index (Heating Plant Emission Rate)

The annual average performance is expressed as the annual rate of carbon dioxide emitted per unit of heat output to the building. Heat output includes heat supplied from auxiliary sources to meet demand under standardised conditions. Credit is given for emissions avoided by reduced demand on the public supply. It is important to recognise that the rate of carbon dioxide emitted is not scalable: even though it is quoted per unit of heat output to the dwelling, it cannot be extended to buildings of different total annual heat demand by simple multiplication.

Calculation of the heating plant emission rate (HPER) requires the heat output to keep the building warm within the heating hours assumed by SAP. Some packages may operate outside these hours. This is catered for by an extended heating factor (X) as noted in Table 10 (see ¶3.10 for details).

---

[2] This is 5/7th of the week.

Table 10: Extended heating factor, *X*	
24 hours/day heating	1.289
16 hours/day heating	1.109
11 hours/day heating	1
Mixed heating	Table A4

The heating plant emission rate is defined as:

$$HPER = (C_f + C_e) / Heat_{gen,HP}$$

where

C_f = (annual fuel generated) x (carbon intensity factor for the fuel)

C_e = (annual net electricity consumed) x (carbon intensity factor for electricity)

$Heat_{gen,HP}$ = the annual heat generated excluding heat loss from an external hot water store but including any produced by secondary heating or hot water heating (see part xx)

The term $(C_f + C_e)$ is the carbon emission of the installation. C_e is negative if the electricity generated is higher than that consumed by the package.

The HPER assumes all electricity generated results in a corresponding reduction in emissions associated with electricity from the national gird.

Calculate the HPER in $kgCO_2$/kWh as:

$$HPER=\{(Fuel_{con} \times CIF_{fuel})+(Elec_{conHP} \times CIF_{elec})\}\times\{X / Heat_{genHP}\}$$

where the carbon intensity factors (CIF) are given in Table 11 and X in Table 10.

If $Elec_{conHP}$ is negative, for electricity use the CIF for the electricity displaced from the public grid. If positive, use the CIF for the “electricity supplied by the public grid.

The HPER is calculated for each of four values of *R* (plant size ratio).

Table 11**: Carbon Intensity factors (selected fuels)** (see Ref. [1], Table 12)	
	kg CO_2 / kWh
Gas	0.194
LPG	0.234
Oil	0.265
Electricity (supplied by the public grid)	0.422
Electricity (displaced from the public grid)	0.568

For other fuels or the latest values, consult the latest source document Ref. [1].

Lower values of HPER indicate lower emissions and hence better overall thermal and electrical performance. Negative values are best.

Table 12:Illustrative fictitious heating plant emission rates (HPER)

Description (11 hour heating unless specified otherwise)	Overall energy efficiency	HPER $kgCO_2$ / kWh
Heat provided with an average heat efficiency of 10% heat to power ratio 1:9 – 24 hour heating [3]	100%	-4.089
Heat provided with an average heat efficiency of 10% and heat to power ratio 1:8	90%	-2.604
Heat provided with an average heat efficiency of 50% heat to power ratio 5:4	90%	-0.066
Heat provided with an average heat efficiency of 70% and heat to power ratio 7:2	90%	-1.018
Heat provided with an average heat efficiency of 100% and no power **(best possible boiler)**	100%	0.194
Heat provided with an average heat efficiency of 50% (heat to power ratio 5:2)	70%	0.161
Heat provided with an average heat efficiency of 90% and no power **(A rated boiler)**	90%	0.216
Heat provided with an average heat efficiency of 90% and no power (24 hour heating) **(non condensing boiler)**	90%	0.278
Heat provided with an average heat efficiency of 70% and no power (24 hour heating)	70%	0.307

No supplementary heating is necessary in all cases

---

[3] Can be heat-led if heat output is of sufficient size

Part 3 : THEORETICAL BACKGROUND

3.1 Terminology

The term “fuel” refers to the fuel burned by the µ-cogen package, such as natural gas, LPG, or oil. Electricity is not a fuel in this context.

The term “net electrical output” refers to the electrical output from the µ-cogen package measured in the laboratory tests, and in some cases may be negative as it includes power used internally within the package. The laboratory test procedure specifies that the power consumption of any internal pump used to circulate water through the external distribution and emission systems is excluded from the measurement.

The term “auxiliary electricity” refers to consumption by components within the heating system other than the µ-cogen package (assumed to be conventional circulator pump and controls).

3.2 Heating season

The heating season is assumed fixed at 243 days per year. The summer season, during which there is hot water demand only, is assumed fixed at the remaining 122 days of the year.

3.3 Hot water demand

The 5.845 kWh/day for the laboratory test regime (see tapping cycle 2, Ref. [11]) is near but not the same as an inferred average usage in the UK. Based on the inferred UK average water heating consumption of 5101 kWh/yr (see Table 31) and on the SAP 2005 algorithms with a heat efficiency of 70%, the useful energy content is 5.420 kWh/yr – see Table 32).

A factor equal to 5.420÷ 5.845 = 0.927 is required to convert the laboratory useful energy to the inferred UK average.

Table 31: Hot water heating energy

	GB use (PJ/yr)	Number of homes Millions	Energy used per home (kWh/yr)	Hot water demand per home kWh/yr (100% efficient heat source)	
			say, 70% efficient	including primary pipe loss	excluding primary pipe loss
Annual hot water load	448.8	24.421	5101	3571	2961
Heating season demand			3396	2377	1971
Summer demand			1704	1194	990

Table 31 also shows the heat requirement for DHW produced by a 100% efficient heat source without primary pipe heat losses (ie from an electric immersion tank). These values are used for a µ-cogen package that cannot provide hot water all the year round.

Table 32: Hot water heating energy using SAP 2005 algorithms

Useful energy litres/day	Useful energy water content kWh /yr	Primary pipe heat loss kWh /yr	Distribution heat loss kWh /yr	Cylinder heat loss kWh /yr	Total
=1980÷365.3	=(61x Nocc+92) x 0.85 x 8.76 footnote (4)	No insulation with cylinder thermostat	=(61x Nocc+92) x 0.15 x 8.76	120 litre tank insulated with 25mm of foam = 0.024 x 120 x 365.3 x0.6	
93.4	1980	610	350	631	3571

3.4 Plant size ratio

The plant size (nominal heat output) is matched to dwelling heating demand to ensure an adequate supply of heat for virtually all the days of the year. This is usually achieved by matching the appliance heat output to the heat loss of dwelling under design conditions. An allowance of hot water and intermittent heating is also usually added, resulting in the appliance being over sized compared to design conditions. The sizing is often expressed as the plant size ratio: the nominal heat output in kW divided by the design heat loss (ie average steady state heat loss in kW under design conditions).

The plant size ratio is: $R = P_{nom}/dhl$

where dhl is the design heat loss calculated in accordance with usual practice (ie BS 5449, Heating Guide – see Ref. [3]).

The default PSR when the plant size is such that auxiliary heating (or supplementary) is only needed to maintain the design temperature during SAP heating hours for 1% of the days of less, over ten years.

This supplementary heating expressed as fraction of the heat generated from a package that can meet the load is:

$$S_f = \frac{(N_{h2} - N_{h1}) \times Q_{100}}{N_{h1} \times Q_{100}} = \frac{(N_{h2} - N_{h1})}{N_{h1}}$$

where N_{h1} is the number of load hours for a µ-cogen package

---

[4] Nocc= 2.853 to get hot water demand the same as the UK average.

N_{h2} is the number of load hours for a µ-cogen package if it were not restricted by output

See ¶3.11.1 and ¶3.11.2 for full definition of the load hours.

3.4.1 Default value

The values of S_f were calculated from the tabulated values of N_{h2} and N_{h1} (Appendix A). The values of *R* when S_f is less than 0.01 are shown in Table 33:

Table 33: Values of plant size ratio when supplementary fraction exceeds 1%.

	Heating 24 hours/day	Heating 16 hours/day	Heating 11 hours/day	Mixed hours
Heating only	0.7	1.0	1.5	0.7

Adopting the simple approach of a single minimum *R*, and to encourage manufacturers to declare dhl ranges, the highest value was selected for the default value (1.5).

3.4.2 Range validity

The main assumption underlying this procedure is that the µ-cogen package is heat-led within certain limits. When the supplementary heating fraction exceeds 50% of the heat generated by the µ-cogen package is not providing most of the heat and therefore deemed not to be heat-led. The minimum R when this occurs can be determined using formula in ¶3.4 above and tabulated values in Appendix A, as shown in Table 34:

Table 34: Lowest plant size ratio when supplementary fraction is less than 50%.

	Heating 24 hours/day	Heating 16 hours/day	Heating 11 hours/day	Mixed hours
Heating only	0.3	0.3	0.4	0.3

Adopting the simple approach of a single minimum *R*, then a valid range for *R* of 0.5 or higher is selected.

3.5 Load profiles

The load profile is the number of days per heating season the µ-cogen is expected to operate within 13 part-load bands. Its derivation is detailed in ¶3.6.

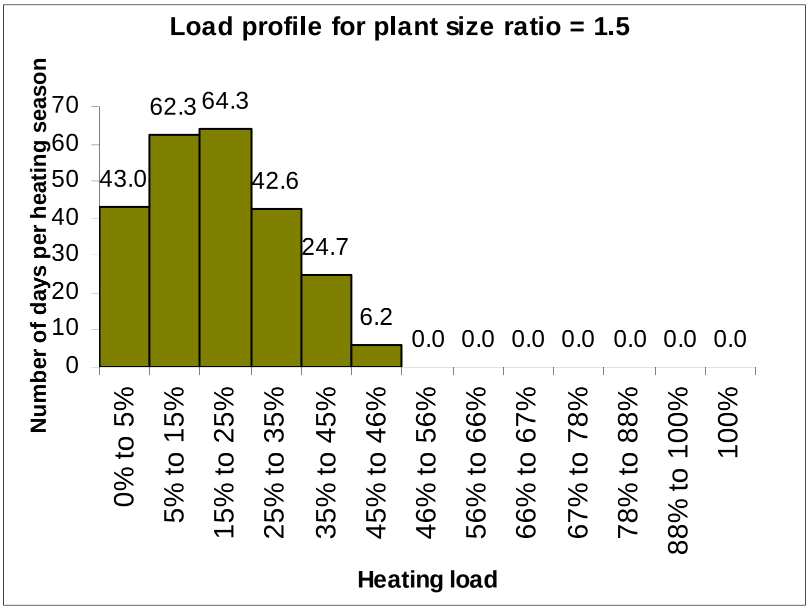
The heating season load profiles were for the following four conditions were derived:

- Regime 1 – 24 hours/day
- Regime 2 – 16 hours/day - unimodal (16 hours daily provided in one period 7.00-23.00)

- Regime 3 – 11 hours/day - bimodal (11 hours of heating provided in two periods 6.00-9.00 and 15.00-23.00)
- Regime 4 – mixed regime - this is a mixture of above three. On cold days when 16-hour heating would provide insufficient heat to maintain the design temperatures during the heating periods, then continuous heating is assumed. When 11-hour heating would provide insufficient heat and the 16-hour case provide sufficient heat, then 16-hour operation is assumed. When 11-hour operation would provide sufficient heat, then 11 hours/day of heating is assumed.

Figure 31 shows the load profile for 11 hours/day heating operation for space heating. Note that, as the load is expressed as a percentage of the maximum daily load the highest load possible over 11 hours is 45.5% (ie 11/24th)

Figure 31: Load profile for space heating and hot water (bimodal)



3.6 Load profile derivation

For each day (ie each mean outside temperature - T_{oi}) and for a specified number of heating hours (h), plant ratio (R), plant size (Q_{nom}), base temperature (Tb), design internal temperature (T_{id} =19°C) and outside design temperature (T_{od}=-1°C) the fractional part-load was estimated from

$$l_i = \left(\frac{(T_b - T_{oi})}{(T_{id} - T_{od})R} + \frac{\mathrm{Q_{dhw}}}{\mathrm{Q_{nom}}} \right)$$

To derive the profile, the number of days with a fractional load within each load band was totalled. Note that, by definition, the part-load is expressed as a percentage of the daily maximum possible load.

The formula consists of two terms:

- the term to left of the plus in the brackets, which is space heating load;
- the term to right of the plus in the brackets, which is DHW load.

The source of the climate temperature data is described next, followed by the derivation of each of the two terms.

3.6.1 Temperature data

The daily mean outside temperatures used were from Kew, London, over the ten-year period 1957-1968, specified as the number of days within given temperature interval, or band. This data was used as it is published (see Ref. [7], Table A2.8). The data was adjusted to the average UK climate by adjusting the degree-day base temperature until the load profile predicted the same number of full load hours (see ¶3.8) to that estimated from data for average UK dwelling in the Domestic Energy Fact File (Ref. [5]).

For each month, the data gives the number of days with a mean daily temperature within ten temperature ranges or bands. The band limits differed for each month, so before numbers in a given band could be summed for the heating season, each band is subdivided into even 0.1°C sub-ranges or bins. For example, for January the range 9.2°C to 10.8°C was divided into sixteen bins of width 0.1°C and the number of days allocated to each bin was scaled by 1/16th.

After allocating the number of days per month in each 0.1°C bin, to estimate the number of days in the heating season within each temperature bin, the number per month was summed over October to May; the assumed heating season in SAP.

3.6.2 Space heating load fraction

For each day of the heating season, based on the mean outside daily temperature, the heating load expressed as a fraction of the maximum daily load was calculated using equation in step 5 below and derived in steps 1 to 4.

1) From “degree-day theory” the average space heating load on day i is:

$$Load_{space,i}(kW) = (T_b - T_{oi})^+ SL(kW / {}^\circ C)$$

(The + superscript means only evaluate the term in brackets if positive)

where SL is the specific heat loss, T_b and T_{oi} is the base temperature and outside temperature on day i respectively.

The base temperature is the average 24-hour inside temperature minus any temperature due to incidental heat gains.

2) From the definition of design heat loss, dhl, it is known on a design day that:

$$dhl(kW) = (T_{id} - T_{od})SL(kW / {}^\circ C)$$

where T_{id} and T_{od} are the internal and external design temperatures

3) Combining the above two equations to eliminate, SL, gives:

$$Load_{space,i}(kW) = \frac{(T_b - T_{oi})^+ dhl}{(T_{id} - T_{od})}$$

4) To keep the dwelling warm 24 hours a day, daily heat load (in kWh) for space heating expressed as fraction of the plant size (Q_{nom}) running for 24 hours the previous equation divided by the plant size times 24:

$$l_i = \frac{(T_b - T_{oi})^+ dhl \times 24}{(T_{di} - T_{do})(P_{nom} \times 24)}$$

5) As $R = \frac{P_{nom}}{dhl}$ then $l_i = \frac{(T_b - T_{oi})^+}{(T_{id} - T_{od})R}$

Of the five terms on the right hand side only the base temperature is unknown. The design temperatures are specified, the mean outside temperature is known from the climate data and R is calculated (Table 31). The base temperature is the mean internal temperature minus the temperature rise due to incidental heat gains (eg solar and metabolic). These two temperatures are discussed in ¶3.7 and ¶3.8.

3.6.3 Domestic hot water service

This is taken as zero for the purposes of the load tables (appendix A); otherwise too many load tables would be required: one for space heating and one each value of the hot water load divided by the maximum package heat output. Too many load tables would make the procedure impractical.

Instead, the domestic hot water service is modelled outside of the load tables (see ¶3.11).

3.7 Mean internal temperature

The mean internal temperature of dwellings depends, among other things, on the duration of the heating period. There are three heating standards to consider.

3.7.1 SAP heating standard

The daily average temperature in the main living areas (zone 1 in SAP) for the standard schedule of 77 hours a week is tabulated in Table 8 of SAP. It is a function of responsiveness of a heating system and heat loss parameter. The heat loss parameter is the specific heat loss divided by the heat floor space that range from 1 to 6 $W/^oC/m^2$. Taking the mid-range value of 3.5 and a responsiveness of 1 (ie, applicable to wet heating systems with radiators) as the typical situation, then the average zone 1 temperature for bimodal operation is 18.48°C.

The temperature difference between the main living areas and the rest of the dwelling (zone 2 in SAP) is tabulated in table 9 of SAP. For control column 2, applicable to thermostat radiator valves in zone 2, and for a heat loss parameter of 3.5, the average temperature differential is 1.79°C.

Assuming the zone 1 fraction is one third (ie two thirds of the ground floor area) gives for the heated part of the dwelling, a mean internal temperature of 17.29°C.

3.7.2 Continuous

For 24-hour operation, the mean temperature is same as internal design temperature of 19°C (ie 21°C – 3°C x 2/3).

3.7.3 Unimodal

The mean internal temperature of unimodal operation (7.00 to 23.00) is not known in SAP and so has to be estimated. It was estimated from the continuous and SAP heating schedule mean internal temperature.

$$T_{ave16} = 0.385T_{id} + 0.615T_{ave77}$$

where T_{ave77} is the mean internal temperature during SAP heating times

T_{id} is the internal design temperature (or temperature during continuous operation)

This was derived by:

i) Considering the temperature during heating on-period and off-period for each hour of the week for the SAP heating times and unimodal times gives.

$$(24\times 7)T_{ave16} = 7\times 16\times T_{id} + 8\times 7\times T_{aveoff\,16} = 112\times T_{id} + 56\times T_{aveoff\,16}$$

$$(24\times 7)T_{ave77} = 7\times 11\times T_{id} + (24\times 7 - 77)\times T_{aveoff\,77} = 77\times T_{id} + 91\times T_{aveoff\,77}$$

where T_{ave16} is the mean internal temperature during unimodal operation

$T_{aveoff16}$ is the average temperature during the off-period of unimodal operation

$T_{aveoff77}$ is the average temperature during the off-period of SAP operation

The SAP heating schedule is 7.00 to 9.00 and 16 .00 to 23.00 in the week and 16.00 to 23.00 at weekends. Therefore in the SAP schedule there are:

- 5 off-periods per week of 7 hours duration
- 7 off-periods per week of 8 hours duration

The unimodal schedule is 7.00 to 23.00 daily.

- 7 off-periods per week of 8 hours duration

ii) Noting that the off-period duration is similar in SAP to the unimodal case therefore the following approximation can be made:

$$T_{aveoff\,77} \cong T_{aveoff\,16}$$

The approximation means one the of $T_{aveoff\,77}$ and $T_{aveoff\,16}$ can be eliminated and by further manipulation of the two equations above the remaining unknowns can be eliminated. That is, multiply the first equation by 91 and the second by 56, subtract the resultant equations to eliminate the remaining term.

iii) Now make T_{ave16} the subject of resultant equation, by moving term T_{id} to the right hand side and dividing by 24 x 7 and combine the coefficients of T_{id} and T_{ave77}

$$T_{ave16} = \frac{((112\times 91) - (77\times 56))}{91\times 168} T_{id} + \left(1 - \frac{((112\times 91) - (77\times 56))}{91\times 168}\right) T_{ave77}$$

v) Reduce to the coefficients to lowest common dominator gives.

$$T_{ave16} = \frac{35}{91} T_{id} + \frac{56}{91} T_{ave77} = 0.385T_{id} + 0.615T_{ave77}$$

Substituting in the values derived for the SAP times and continuous heating above gives

$$T_{ave16} = 0.385\times 17.29 + 0.615\times 19 = 18.3^{\circ}\mathrm{C}$$

This is used to derive the heating load profile for unimodal operation.

3.8 Base temperature

The base temperature is the mean internal temperature minus temperature rise due to incidental heat gains from people, lighting, appliances, DHW, and solar gains inside the dwelling.

To determine temperature rise due to incidental heat gains, an arbitrary value was selected first and a load profile generated. The number hours per heating season an appliance would run at full load was calculated from the resultant profile, assuming the bimodal case. Repeated values were selected until the average number of hours at full load match those derived from data in the Domestic Energy Fact file data – 4.85 hours (see below). This adjusts the degree-days to match the UK average.

3.8.1 Average load hours

Data from the Domestic Energy Fact File (Ref [5]) was used to estimate the average number of hours that an appliance would need to operate at maximum load to meet the average UK heating and hot water consumption during the heating season.

The numbers of hours were as follows:

Average efficiency x heating season consumption /(no of days x plant size)

70% x 17286 [5] /(243 x P_{nom} [6]) = 4.85 hours

3.9 Mixed heating regime

It is possible that a µ-cogen package may not be able to provide sufficient heat to maintain the dwelling at the design temperature during the heating hours, if the package only operates 11 hours/day or 16 hours/day. In these circumstances the number of hours is increased to 16 hours/day and 24 hours/day respectively. This catered for in the mixed results regime.

The option of modelling a gradual increase in the number of hours, as the days get colder was considered, but this is impractical in SAP. SAP can only represents 77 hours a week heating and only knows the mean internal temperature for continuous heating because it is the design temperature. Further sophistication is impossible without introducing new information into SAP.

For the mixed heating regime,

- The number of days requiring continuous heating is when the fractional load as calculated in ¶3.6 exceeds 16/24.
- The number of days requiring 16 hours/day is when the load fraction lies higher than 11/24 and lower or equal to 16/24.
- The number of days requiring 11 hours/days is when the load fraction is 11/24 or lower.

---

[5] 50 GJ (see table 25, ref [3]) x 277.8 + 3396 (see Table 31)

[6] P_{nom} = dhl x 1.7 = 6.040 x 1.7 = 10.268 kW (The dhl estimated from average 276 W/K, page ref[3] taking account of the design temperature difference and higher ventilation in a design calculation.

In the unlikely, but possible, case where the fractional load exceeds 100%, a heating supplement is estimated (see Appendix 10 item 10)

3.10 Extended heating factor

The package can be assessed in one of four modes of operation: 24 hours/day; 16 hours/day; 11 hours per day, or a mixture of all three. When operating for more than the SAP average of 11 hours/day extra energy is consumed because the dwelling is heated for longer than the standard SAP hours.

In the intermediate results to account for this extra energy required, the number of days the appliance would run at 24 hours/day or 16 hours/day is used to revise the mean internal temperature in models such as SAP.

In the seasonal performance index an extended heating factor is applied instead. It is:

$$X = \frac{N_{h2,24}}{N_{h2,11}}$$

$N_{h2,24}$ is the number of loads hours per heating season for 24 hour heating

$N_{h2,11}$ is the number of load hours per heating for 11 hour heating

$N_{h2} = 24\sum_{i=1}^{243} l_i$ for all days including those greater than 100%.

The values are tabulated in table A1 to A4. See 3.11 for a fuller explanation of the number of load hours.

3.11 Auxiliary heating

A space heating supplement is applied when the package cannot meet the design temperature when operating in one of four modes throughout the heating season.

The concept of load hours is introduced as it is useful aid to estimate heat generated and electricity consumed.

3.11.1 Load hours

The heat generated during the heating season for space heating is the summation:

$$\sum \text{(part-load} \times \text{number of days at part load)}$$

More precisely for fractional load, l_i on day, i, and the maximum fraction load $l_{\max}$ for the assessment regime, the heat generated for space heating is:

$$Heat_{sp} = \sum_{i=1 \text{to} 243}^{\text{when } l_i < 1} (Q_{li}) + \sum_{i=1 \text{to} 243}^{\text{when } l_i \geq l_{\max}} (Q_{l_{\max}})$$

where Q is the daily heat generated at the fractional load indicated by the subscript.

The first summation is over the number of days when the load can be met by the package and second summation is over the days when the load is limited to maximum output.

Noting the daily heat generated at fractional load l_i is $Q_{li} = Q_{100} \times l_i$ then:

$$Heat_{sp} = \sum_{i=1\text{to}243}^{\text{when } l_i<1} (l_i \times 24 \times \tfrac{Q_{100}}{24}) + \sum_{i=1\text{to}243}^{\text{when } l_i \geq l_{\max}} (24 \times l_{\max} \times \tfrac{Q_{100}}{24})$$

$l_{\max}$ is the maximum fractional load for the heating regime (ie 11/24, 16/24 or 24/24)

l_i is the part load fraction on day i of the heating season.

Q_{100} is the daily heated generated during the 100% load test.

Defining the “load hours” as:

$$N_{h1} = \sum_{i=1\text{to}243}^{\text{when} l_i<1} (l_i \times 24) + \sum_{i=1 to 243}^{\text{when} l_i \geq l_{\max}} (24 \times l_{\max})$$

gives the heat generated for space heating as:

$$Heat_{sp} = \tfrac{Q_{100}}{24} \times N_{h1} \qquad \text{equation 3.11.1}$$

The load hours is evaluated solely from the load profile making it a useful quantity to tabulate and to estimate the heat generated from. Equation 3.11.1 is important and used to calculate the heat generated for space heating.

3.11.2 Load hours with unrestrcited output

Another convenient concept is the number of loads that would occur if the output was unrestricted t, N_{h2} ,

$$N_{h2} = \sum_{i=1 to 243}^{li \leq l \max} (l_i \times 24) + \sum_{i=1 to 243}^{li > l \max} (l_i \times 24) = 24 \sum_{i=1 to 243}^{\text{all } i} (l_i)$$

The heat generated in the heating season without the restricted output is:

$$Heat_{sp},_{unres} = \tfrac{Q_{100}}{24} \times N_{h2} \qquad \text{equation 3.11.2}$$

3.11.3 Supplementary heat magniture

The magnitude of the supplement is the difference between the heat generated with and without a restricted output.

$$Heat_{aux} = Heat_{hs},_{unres} - Heat_{hs}$$

Using equation 3.11.1 and 3.11.2 the supplement is:

$$Heat_{aux} = \frac{Q_{100}}{24} \times (N_{h2} - N_{h1})$$

The values of N_{h2} and N_{h1} are function of heat profile only varying with heating regime and plant size ratio. Values are tabulated in A1 to A4.

When the package can provide all the heat generate to keep the dwelling warm during heating hours, the load hours N_{h2} and N_{h1} are the same and hence the supplementary heat requirement is zero as expected.

The supplement only applies to the space heating, in other words it is assumed that the package can provide a satisfactory DHW service.

3.12 Fuel consumed and electricity generated

3.12.1 Summer hot water service

The scaling factor of 0.927 converts (¶3.3) the heat generated in the hot water tests to UK daily average. Therefore the fuel consumed, $Fuel_{sum}$, in the summer season is simply the number of days in the summer, 122, multiplied by the fuel consumed in the hot water test, F_{w}, and multiplied the conversion factor, that is:

$$Fuel_{sum} = F_W \times 122 \times 0.927$$

Similarly, the electricity generated (E_W is the electricity generated in the DHW test):

$$Elec_{sum} = E_W \times 122 \times 0.927$$

And the heat generated (Q_W is the heat generated in the DHW test):

$$Heat_{sum} = (Q_W \times 122 \times 0.927)$$

3.12.2 Heating season

Here the fuel consumed during the heating season is estimated taking into account any reduction caused by an undersized package. First the space heating component is considered.

The fuel consumed during the heating season for space heating is

$$Fuel_{sp} = \sum_{l=0to1} (N_l F_l) = F_T \qquad \text{equation 3.12.1}$$

F_T, is the fuel total in Table 6. N_l is the number of days at fractional load l and varies with heating regime and plant ratio.

The DHW consumption is now considered. To keep the number of load tables down to one per heating regime, the DHW load in the heating season was omitted from the load tables and added as follows instead.

$$Fuel_{hs} = Fuel_{sp} + \left(\frac{heat_{hs,dhw}}{\eta_{hs.dhw}} \right)$$

$Fuel_{hs}$ is the fuel consumed is heating season

$heat_{hs,dhw}$ is the heat generated due to DHW production in the heating season.

$\eta_{hs.dhw}$ is the thermal efficiency of the production of DHW in the heating season.

Assuming heat efficiency of generating hot water in the heating season is the same as space heating efficiency[7] then equation 3.12.1 becomes:

$$Fuel_{hs} = Fuel_{sp} + \frac{heat_{hs,dhw}}{\frac{heat_{sp}}{Fuel_{sp}}} \qquad \text{equation 3.12.2}$$

Using 3.11.1 (see 3.11) to eliminate $heat_{sp}$ and 3.12.1 to eliminate $Fuel_{sp}$ equation 3.12.2 becomes:

$$Fuel_{hs} = F_T \times \left(1 + \frac{heat_{hs,dhw}}{\frac{Q_{100}}{24} \times N_{h1}} \right) \qquad \text{equation 3.12.3}$$

The only unknown is $heat_{hs,dhw}$, the DHW heat generated in the heating season. This is assumed to be the same as the UK average and derived in ¶3.14.

It also follows that the thermal efficiency in the heating season is:

$$\eta_{thermal,hs} = \frac{\frac{Q_{100}}{24} \times N_{h1}}{F_T}$$

A similar argument applies to the electricity generated giving:

$$Elec_{hs} = E_T \times \left(1 + \frac{heat_{hs,dhw}}{\frac{Q_{100}}{24} \times N_{h1}} \right)$$

3.13 Auxiliary electricity consumed

If the package contains an external pump and its consumption is subtracted from the measured electricity generated, the auxiliary electricity is set to zero.

If the electricity generated is not offset by the power from an internal central heating pump, then the electricity consumed by a circulator pump is set to 130 kWh per year: the value used in SAP 2005. It may change in the future.

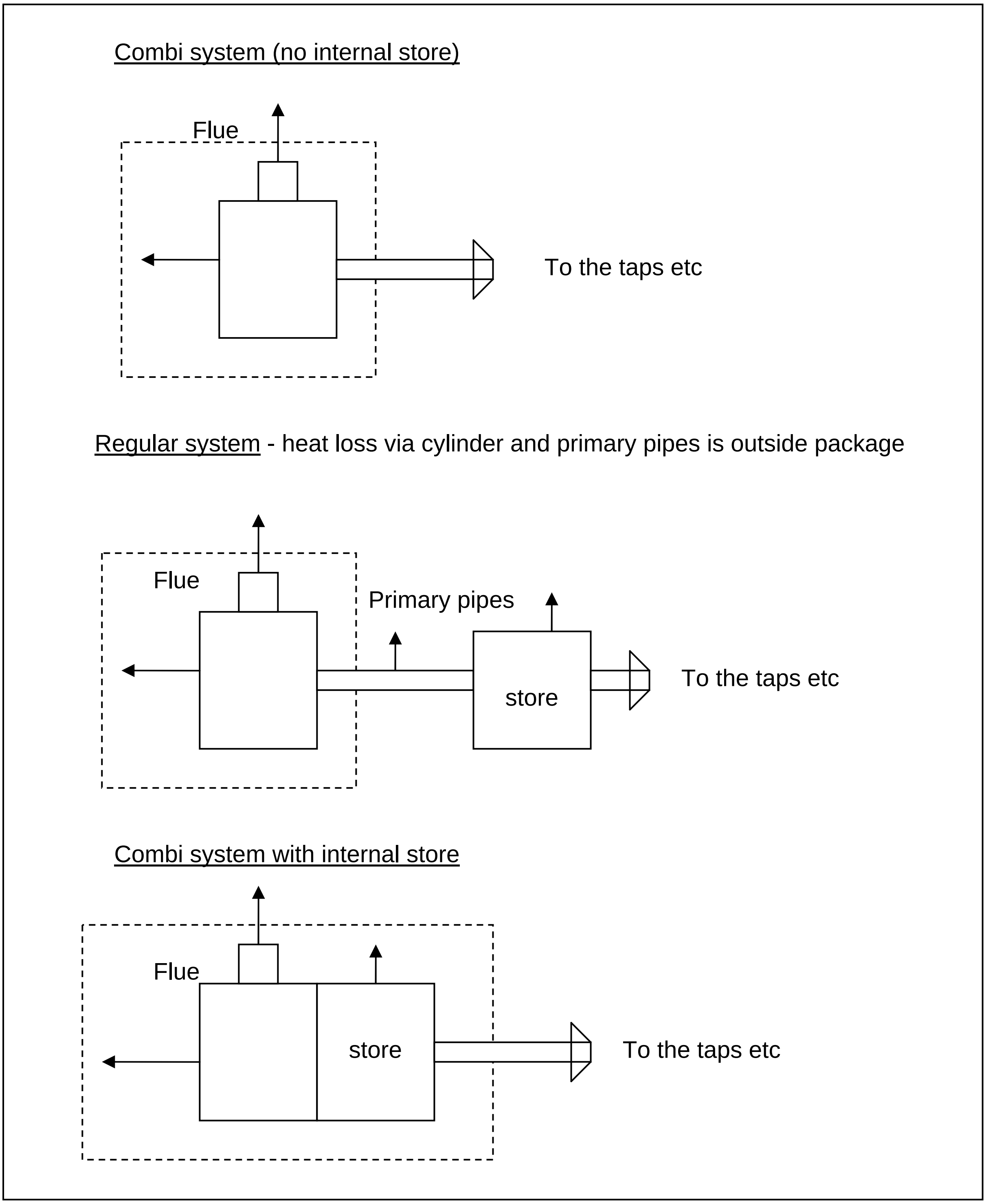
The auxiliary electricity consumed is only used in the determination of seasonal performance index.

---

[7] This is cautious but necessary assumption to reduce the number of load tables.

It is anticipated that electricity consumed by fans in the package is accounted for in the measured generated electricity, and so does not need assigning separately.

3.14 Heat generated



Combi system (no internal store)

Regular system - heat loss via cylinder and primary pipes is outside package

Combi system with internal store

Figure 32 Illustration of heat flow from three package types

The boundary of the package differs depending on package type as illustrated above. For a regular package the hot water cylinder is external to the package and for a combination package any hot water store is within in the package. This means two definitions of heat generated are required: one for HPER purposes and one SAP purposes.

By definition, that the thermal efficiency is the heat produced divided by the fuel consumed. The heat produced (and not the fuel consumed) will include or exclude any heat loss associated with storing any hot water depending on the location of the package boundary. (The measured fuel consumed will always include the energy required to keep any stored water hot).

This means domestic water efficiency measured in the PAS 67 tests is the efficiency at the entry of the hot water distribution system.

The energy consequences for heating and water heating are now discussed in parts 3.14.1 to 3.14.4.

3.14.1 Annual heat for SAP

The DHW efficiency in SAP is the same as that measured for combi packages (CombiPk) but not the same for regular packages RegPk (for RegPk the SAP efficiency is at the entry of the hot water cylinder).

So for a combi package, any heat lost associated with hot water storage is already included in the heat efficiency and therefore

- storage, primary circuit heat loss and combi heat loss must not be included separately in SAP (that is, SAP boxes 45, 48 and 49 are set to zero).

For a *RegPK* the heat expected by SAP is that entering the cylinder. During the DHW test this is not measured directly so requires additional calibration tests. The additional calibration tests involve an electric heater to determine the power required to maintain the cylinder and primary pipes at a nominal 25K and 45K above ambient conditions. The average temperature of the cylinder and pipes is measured during the 24-hour test is combined with calibrated data to estimate the heat losses during the 24-hour test (see appendix C for details).

The annual amount of heat produced associated with stored hot water outside the package is:

$$Heat_{hwstbylab} = + Q_{hwstbylab} \text{ x } 365$$

where $Q_{hwstbylab}$ is the daily heat produced to keep the cylinder and primary pipes warm hot - estimated from cylinder and primary pipe temperatures and the calibration data (see appendix C for details).

3.14.2 Annual generated for SAP purposes

The annual heat generated from the hot water of hot water is number of days multiplied by the daily heat generated in the hot water test, Q_W , and by the conversion factor 0.927. The factor converts the heat of water drawn-off in the test to the inferred UK daily average (for 0.927 see ¶3.3).

Firstly ignoring any losses due to storing hot water then the heat generated from hot water production (or the energy content of the hot water drawn-off) is:

In the heating season:

$$Heat_{hs,hw} = Q_W \times 243 \times 0.927 = Q_W \times 225$$

In the summer season:

$$Heat_{sum} = 122 \times 0.927 \times Q_W = 113 \times Q_W$$

The annual heat generated for SAP purposes is the heat generated for space heating plus DHW heat generated in the heating and the summer season for hot water. This is:

$$Heat_{gen,sap} = Heat_{sp} + Heat_{hs,hw} + Heat_{sum}$$

Now re-introducing any heat loss associated with an external hot water store (see 3.14.1) and substituting for $Heat_{sp}$ using 3.11.1 gives

$$Heat_{gen,sap} = \frac{Q_{100}}{24} N_{h1} + Heat_{hs,hw} + Heat_{sum} + Heat_{hwstbylab}$$

N_{h1} is number of load hours in tables A1 to A4

Q_{100} is the heat output for the 100% load test

$Heat_{hwstbylab}$ (see 3.14.1).

3.14.3 Annual heat generated for HPER purposes

In terms of the seasonal performance index, the measured fuel consumed and electricity generated contains the energy required to heat any hot water store, whether internal or external to the package, so the numerator of the rating equation (¶2.14) is the same for a regular and combination package.

The definition of the dominator of the HPER equation is the heat produced by the package, plus heat assoicated with any auxilary heating or water heating. For water heating this is the energy of the hot water drawn off only.

Therefore, included in the demoniator (i.e. the produced by the package and anxilairy equipment) must be the heat produced by the auxilary space heating or water heating plus the energy content of the hot water drawn-off. This is:

$$Heat_{gen,HP} = \frac{Q_{100}}{24} N_{h1} + Heat_{hs,hw} + Heat_{sum} + Heat_{aux} + HW_{aux}$$

3.14.4 Storage combi packages

It was recognised with combi package with large store the amount of energy stored (or lost) during a DHW test may skew the results. Therefore, for CombiPk with 15 litres or more of internal water, until improvements to the test procedure can be made, it was decided that the heat efficiency and net electricity produced per unit of heat at 5% load during space heating would serve as a better proxy to hot water test data.

3.15 Part-load intervals

The reasons for the choice of the part-load intervals in Table 35 are noted here.

Table 35 Load intervals

Lower limit (included)	Mid-point	Upper limit (excluded)	Mode of operation
0%	2.5%	5%	C, U or B
5%	10.0%	15%	C, U or B
15%	20.0%	25%	C, U or B
25%	30.0%	35%	C, U or B
35%	40.0%	45%	C, U or B
45%	45.5%	46%	C, U or B
46%	51.0%	56%	C or U
56%	61.0%	66%	C or U
66%	66.5%	67%	C or U
67%	72.5%	78%	C
78%	83.0%	88%	C
88%	94.0%	100%	C
100%	100.0%	100%	C

C – continuous (24 hours/day); U – Unimodal and B – Bimodal

Part-load is expressed as percentage of the maximum possible daily load.

Initially ten even 10% load intervals were considered. However, in the case when package cannot provide sufficient heat all the year round because of its limited size, there would be a large number of days when the load is exactly 11/24 (45.5%) when in bimodal operation, 16/24 (66.5%) when in unimodal operation and 100% when operating 24 hours a day. If the part-load intervals were evenly spread this would cause the profile to be biased and be unrepresentative. To prevent this bias, three narrow part-load intervals were introduced indicated by the shaded entries in Table 35.

To reduce the amount of linear interpolation required the part-load intervals were centred on the part-load measurement points: namely 5-15% and 25%-35% resulting in a 0-5% band.

Remaining intervals were selected at approximately 10% intervals but taking note of three exact intervals needed, giving 13 load intervals in total.

3.16 Linear interpolation

To generate the 13 fuel consumption and net electricity generated values, linear interpolation is necessary between the results immediately above and below.

For 24 hours/day heating this is straightforward as all part load measurements are in continuous operation and Interpolation is between any two of 0%, x1, x2 and 100%. (x1 and x2 are the actual loads for the nominal 10% and 30% tests)

For 16 hours/day heating, linear interpolation uses the values at the maximum load for uni-modal operation (16/24 approximately 66.5%). This latter figure is not measured but estimated from the 100% continuous and standby test result.

$$F_{66.5} = {}^{16}/_{24} \times F_{100} + {}^{8}/_{24} F_0$$

For 11 hours/day heating, linear interpolation uses the value at the maximum load (11/24 approximately 45.5%) for bimodal operation. This latter figure is not measured but estimated from the 100% continuous and standby test result.

$$F_{45.5} = {}^{11}/_{24} \times F_{100} + {}^{13}/_{24} F_0$$

For the mixed heating regime linear interpolation must be between values of the same operation mode. For the bimodal days (loads equal to 45.5% or lower) the two values available are the 10% bimodal result and the estimated value $F_{45.5}$.

For unimodal days (loads between 50% and 66.5%) the two values available are the 30% unimodal result and the estimated value $F_{66.5}$.

For continuous days (loads above 66.5%) the pairs used in the interpolation are the 100% continuous result and the result at a part-load of x2 estimated from the unimodal result $(F_{x2,u})$ using:

$$F_{x2,c}=F_{x2,u} - (8/16 \times F_0)$$

The formula equates the fuel consumed at a nominal load of 30% over 24 hours of continuous heating to that over a heating on-time of 16 hours and off-time of 8, by subtracting the amount of the fuel consumed (if any) during the off-period estimated from the standby fuel consumption.

A similar argument applies to the electricity generated giving equivalent equations for the electricity generated.

3.17 Requirements for a SAP dataset

During a SAP assessment for a dwelling the design heat loss (dhl) is estimated. This can readily be combined with nominal heat output to produce plant size ratio, *R*.

However, to complete the SAP assessment for a cogen package, as indicated below, a two-way flow of information between the SAP assessment and method would be required. This causes problems because a separate cogen calculator for SAP assessors is not feasible.

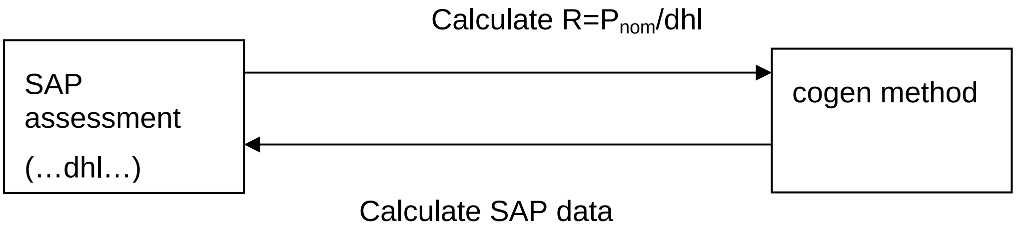


Figure 33 Problem of the two-way flow of data

To obviate the two-way flow of information and retain the method outside SAP, it was decided to produce several datasets of results for SAP, each for a single plant size ratio. Values at the plant ratio calculated within SAP can then be estimated by interpolation between dataset values.

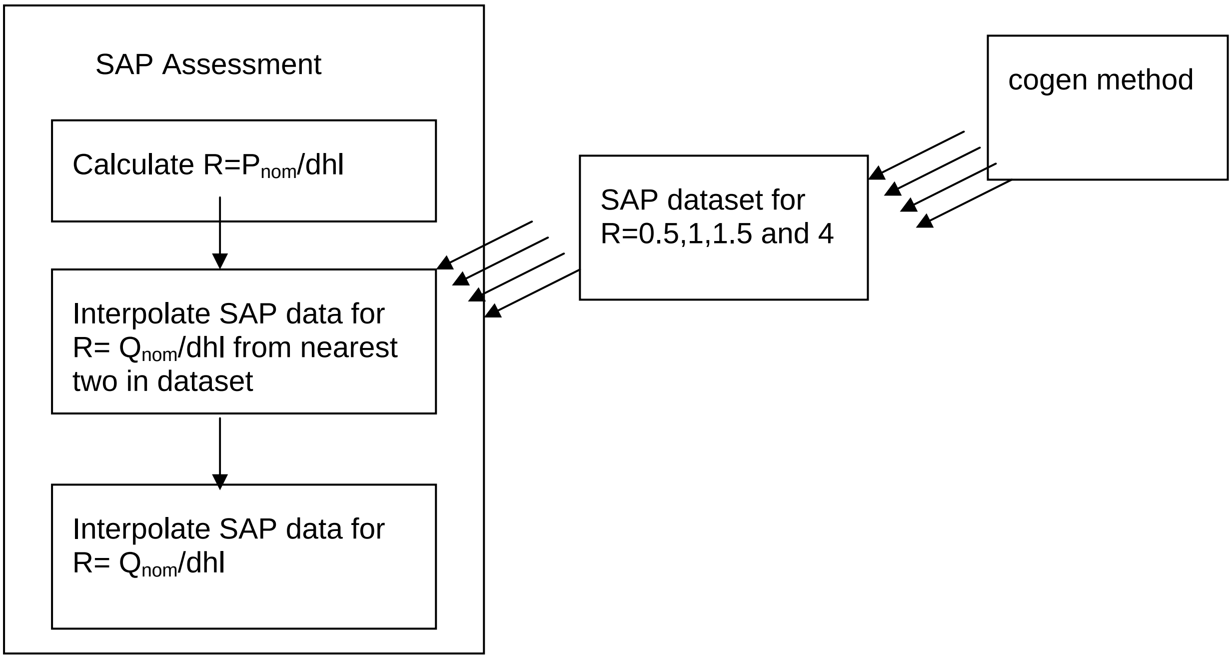


Figure 34 One-way information flow solution.

The values of 0.5, 1.0, 1.5 and 4.0 were selected because the supplementary heating fraction is approximately linear between each pair, as illustrated below.

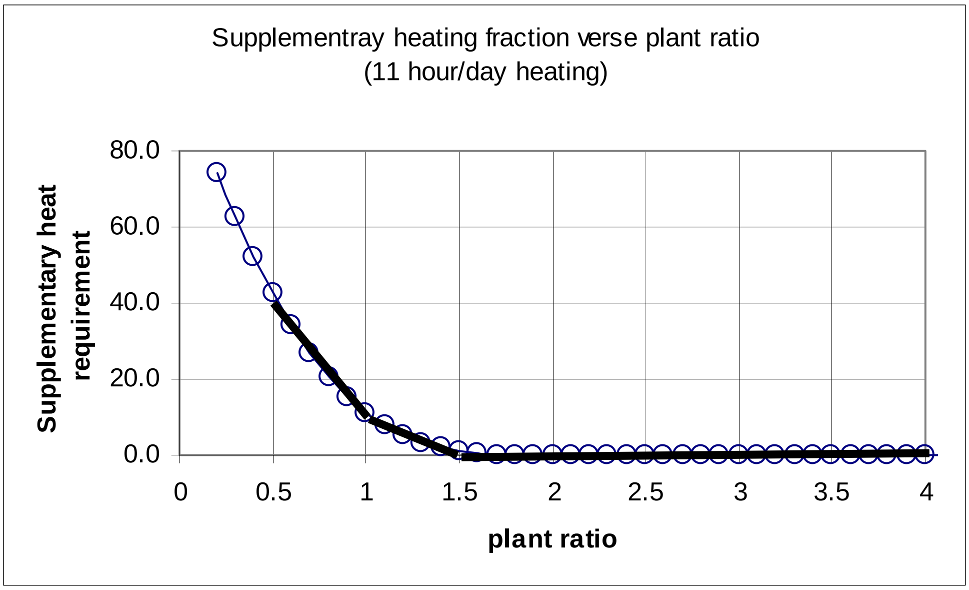


Figure 35 Linear approximation of supplementary heating fraction

REFERENCES

[1] *The Government's Standard Assessment Procedure for Energy Rating of Dwellings*, 2005 Edition 2008 update, BRE, January 2008.

[2] *Publicly available standard 67, Laboratory tests to determine the heating and electrical performance of heat-led micro-cogeneration packages primarily intended for heating dwellings*, BSI, 2008.

[3] *Specification for forced circulation hot water central heating systems for domestic premises*, BS5449: 1990 incorporating Amendment No.1, March 2002

[4] *Domestic heating design guide,* HVCA and CIBSE, October 2000

[5] *Domestic energy fact file 2003,* L D Shorrock and J I Utley, BRE publication BR457

[6] *Development of a specification for Micro-CHP trials – monitoring requirements. Final Report*, G Henderson and C Martin, EST, 24 May 2002

[7] *Chartered Institute of Building Services Engineers Guide*, Volume A, Design Data, 1988

[8] *Alternative Road Transport Fuels - A Preliminary Life Cycle Study for the UK*, M P Gover, S A Collings, G S Hitchcock, D P Moon and G T Wilkins, ETSU, Mar 1996

[9] *Heating systems in buildings - Method for calculation of system energy requirements and system efficiencies - Part 4-4: Heat generation systems, building-integrated cogeneration systems*, BS EN 15316-4-4:2007, BSI, October 2007

[10] *Boiler Efficiency Database*, www.sedbuk.com

[11] *Gas-fired domestic appliances producing hot water — Appliances not exceeding 70 kW heat input and 300 l water storage capacity — Part 2: Assessment of energy consumption*, BS EN13203-2:2006, BSI, 2006.

[12] *Analysis of errors in the domestic hot water efficiency test in PAS 67, Hayton J, BRE, Client report number 241-304, December 2007.*

APPENDIX A: Heat load profiles

Table A1: 24 hours/day heating load profiles - PAS 67 Table 2 **Regime 1**

R	0.5	0.6	0.7	0.8	0.9	1	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2	2.1	2.2	2.3	2.4	2.5
Part-load	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days
2.5%	12.1	12.5	13.2	13.9	14.6	15.4	16.3	17.1	17.9	18.8	19.7	20.7	21.6	22.6	23.6	24.7	25.8	26.9	27.9	29.3	30.7
10.0%	7.7	10.0	12.6	15.4	19.2	23.9	28.6	33.4	38.3	43.5	48.6	54.2	60.1	65.3	70.3	75.7	81.9	88.0	93.8	99.7	105.4
20.0%	11.0	16.8	22.9	28.9	34.5	40.3	44.9	49.9	56.2	61.9	67.9	72.2	75.2	78.3	80.2	81.2	82.0	82.1	82.0	80.9	79.3
30.0%	17.9	22.9	28.6	33.6	39.4	44.6	50.8	54.6	55.4	54.4	53.5	52.6	51.7	50.5	49.5	47.3	44.5	40.6	36.2	31.3	26.6
40.0%	19.6	25.6	30.5	37.1	41.5	41.9	39.5	39.2	38.4	38.0	35.6	32.2	28.6	23.5	17.9	13.4	8.6	5.3	3.1	1.8	1.0
45.5%	1.9	1.9	2.5	2.4	1.9	3.4	3.2	2.8	2.5	2.2	2.2	2.2	1.2	0.5	0.4	0.2	0.1	0.1	0	0	0
51.0%	21.7	27.5	32.5	33.0	30.5	30.2	30.1	27.5	24.1	19.6	13.7	8.1	4.4	2.4	1.0	0.4	0.2	0	0	0	0
61.0%	23.0	27.7	26.9	25.3	25.8	23.1	19.4	14.7	8.9	4.2	1.8	0.7	0.3	0	0	0	0	0	0	0	0
66.5%	2.4	2.2	1.5	3.1	2.4	1.6	1.4	0.5	0.4	0.1	0.1	0	0	0	0	0	0	0	0	0	0
72.5%	25.5	24.0	24.5	21.6	19.1	13.9	7.4	3.0	1.0	0.3	0	0	0	0	0	0	0	0	0	0	0
83.0%	19.8	18.6	17.7	14.6	10.2	3.7	1.2	0.3	0	0	0	0	0	0	0	0	0	0	0	0	0
94.0%	19.1	20.2	15.7	10.7	3.2	0.9	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
100.0%	61.4	33.1	14.0	3.3	0.7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N_{h1} hours	3805	3359	2958	2612	2326	2094	1904	1745	1611	1496	1396	1309	1232	1163	1102	1047	997	952	910	873	838
N_{h2} hours	4188	3490	2991	2618	2327	2094	1904	1745	1611	1496	1396	1309	1232	1163	1102	1047	997	952	910	873	838
R	2.6	2.7	2.8	2.9	3	3.1	3.2	3.3	3.4	3.5	3.6	3.7	3.8	3.9	4	4.1	4.2	4.3	4.4	4.5	4.6 or more
Part-load	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days
2.5%	32.3	33.8	35.6	37.5	39.4	41.1	43.0	44.9	46.8	48.7	50.5	52.4	54.4	56.3	58.2	60.2	62.3	64.4	66.4	68.3	70.2
10.0%	110.5	115.4	119.4	123.2	126.8	130.0	132.7	135.2	138.0	141.0	143.7	145.9	148.2	149.9	151.6	153.1	154.3	155.5	156.5	157.0	157.3
20.0%	78.2	76.0	73.9	72.1	69.6	66.9	64.0	60.6	56.7	52.4	48.2	44.3	40.2	36.7	33.1	29.7	26.4	23.1	20.1	17.8	15.5
30.0%	21.6	17.5	13.9	10.3	7.2	5.0	3.3	2.4	1.5	1.0	0.7	0.4	0.3	0.1	0	0	0	0	0	0	0
40.0%	0.5	0.3	0.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45.5%	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
51.0%	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
61.0%	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
66.5%	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
72.5%	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
83.0%	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
94.0%	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
100.0%	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N_{h1} hours	805	776	748	722	698	675	654	635	616	598	582	566	551	537	524	511	499	487	476	465	455
N_{h2} hours	805	776	748	722	698	675	654	635	616	598	582	566	551	537	524	511	499	487	476	465	455

R – plant size ratio; N_{h1} – number of load hours per year;

N_{h2} – N_{h1} plus the load hours that exceed the maximum capacity

Table A2: 16 hours/day heating load profiles - PAS 67 Table 2 **Regime 2**

R ratio	0.5	0.6	0.7	0.8	0.9	1	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2	2.1	2.2	2.3	2.4	2.5
Part-load	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days
2.5%	19.7	20.7	21.6	22.6	23.6	24.7	25.8	26.9	27.9	29.3	30.7	32.3	33.8	35.6	37.5	39.4	41.1	43.0	44.9	46.8	48.7
10.0%	11.0	15.0	19.6	24.2	28.8	33.5	38.6	43.3	49.3	54.4	59.1	63.8	69.0	74.5	79.8	84.8	90.2	95.4	100.0	104.4	108.3
20.0%	17.9	22.6	27.1	32.8	37.4	42.2	48.1	54.0	58.9	63.4	67.1	70.0	71.4	71.5	72.4	72.8	72.4	71.5	70.6	69.7	68.3
30.0%	19.6	25.5	30.0	35.3	41.6	46.7	48.2	48.5	47.0	47.1	46.8	46.0	45.7	44.4	41.5	38.8	35.0	30.6	26.1	21.3	17.4
40.0%	21.5	26.4	33.1	36.3	36.5	34.5	34.9	34.8	34.5	31.8	29.0	25.4	20.4	15.7	11.3	7.0	4.2	2.5	1.4	0.8	0.4
45.5%	2.1	2.3	4.8	3.9	3.3	3.2	2.8	3.6	3.2	2.2	2.0	1.2	0.7	0.4	0.2	0.1	0.0	0	0	0	0
51.0%	23.0	28.1	28.2	26.6	27.3	27.4	25.3	21.7	17.5	12.8	7.5	3.9	2.0	0.9	0.4	0.2	0	0	0	0	0
61.0%	23.5	23.8	22.0	23.3	21.5	18.3	14.3	8.6	4.1	1.9	0.8	0.3	0	0	0	0	0	0	0	0	0
66.5%	104.6	78.6	56.6	38.0	23.1	12.6	5.0	1.7	0.5	0.1	0	0	0	0	0	0	0	0	0	0	0
72.5%	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
83.0%	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
94.0%	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
100.0%	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N_{h1} hours	2780	2554	2340	2139	1953	1784	1633	1500	1386	1287	1201	1126	1060	1001	948	901	858	819	784	751	721
N_{h2} hours	3604	3003	2574	2253	2002	1802	1638	1502	1386	1287	1201	1126	1060	1001	948	901	858	819	784	751	721

R ratio	2.6	2.7	2.8	2.9	3	3.1	3.2	3.3	3.4	3.5	3.6	3.7	3.8	3.9	4	4.1	4.2	4.3	4.4	4.5	4.6 or more
Part-load	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days
2.5%	50.5	52.4	54.4	56.3	58.2	60.2	62.3	64.4	66.4	68.3	70.2	72.6	74.9	77.3	79.6	81.7	83.7	85.8	87.9	89.8	91.9
10.0%	112.0	115.4	118.3	120.8	123.4	126.2	129.0	131.1	133.4	135.5	137.2	138.5	139.5	140.4	141.3	142.0	142.3	142.4	142.6	142.9	142.8
20.0%	66.4	64.9	63.1	60.9	58.0	54.3	50.2	46.5	42.6	38.9	35.3	31.9	28.6	25.3	22.1	19.3	17.0	14.8	12.6	10.3	8.3
30.0%	13.8	10.3	7.2	5.0	3.3	2.4	1.5	1.0	0.7	0.4	0.3	0.1	0	0	0	0	0	0	0	0	0
40.0%	0.2	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45.5%	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
51.0%	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
61.0%	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
66.5%	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
72.5%	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
83.0%	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
94.0%	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
100.0%	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N_{h1} hours	693	667	644	621	601	581	563	546	530	515	501	487	474	462	451	440	429	419	410	400	392
N_{h2} hours	693	667	644	621	601	581	563	546	530	515	501	487	474	462	451	440	429	419	410	400	392

R – plant size ratio; N_{h1} – number of load hours per year;

N_{h2} – N_{h1} plus the load hours that exceed the maximum capacity

Table A3: 11 hours/day heating load profiles - PAS 67 Table 2 **Regime 3**

R ratio	0.5	0.6	0.7	0.8	0.9	1	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2	2.1	2.2	2.3	2.4	2.5
Part-load	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days
2.5%	26.9	27.9	29.3	30.7	32.3	33.8	35.6	37.5	39.4	41.1	43.0	44.9	46.8	48.7	50.5	52.4	54.4	56.3	58.2	60.2	62.3
10.0%	16.1	20.7	25.1	29.4	34.1	38.8	44.0	48.3	52.5	57.1	62.3	67.6	72.8	77.9	83.2	88.1	92.8	96.8	100.5	104.2	107.3
20.0%	19.3	23.9	29.4	33.8	38.9	44.7	49.4	54.8	59.3	62.4	64.3	64.6	65.2	66.2	66.0	65.6	65.1	64.6	64.1	62.4	60.9
30.0%	21.4	25.7	31.1	37.4	41.9	43.4	43.7	42.7	43.0	43.1	42.6	42.8	41.2	38.4	36.0	32.6	28.3	23.9	19.3	15.9	12.4
40.0%	21.5	28.3	32.2	33.0	31.5	32.1	32.3	32.3	30.3	27.4	24.7	20.0	15.4	11.1	6.9	4.1	2.5	1.4	0.8	0.4	0.2
45.5%	137.7	116.4	95.9	78.6	64.4	50.3	38.0	27.5	18.5	11.8	6.2	3.1	1.5	0.7	0.3	0.1	0	0	0	0	0
51.0%	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
61.0%	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
66.5%	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
72.5%	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
83.0%	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
94.0%	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
100.0%	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N_{h1} hours	2017	1911	1801	1693	1589	1491	1397	1309	1226	1149	1078	1013	955	902	855	812	774	738	706	677	650
N_{h2} hours	3249	2708	2321	2031	1805	1625	1477	1354	1250	1160	1083	1015	956	903	855	812	774	738	706	677	650

R ratio	2.6	2.7	2.8	2.9	3	3.1	3.2	3.3	3.4	3.5	3.6	3.7	3.8	3.9	4	4.1	4.2	4.3	4.4	4.5	4.6 or more
Part-load	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days
2.5%	64.4	66.4	68.3	70.2	72.6	74.9	77.3	79.6	81.7	83.7	85.8	87.9	89.8	91.9	93.9	96.1	98.3	100.4	102.8	105.3	107.7
10.0%	109.7	112.2	114.9	117.8	120.2	122.1	123.9	125.4	127.0	128.4	129.7	130.9	132.1	132.6	132.8	132.9	132.9	133.1	132.4	131.6	130.3
20.0%	60.0	58.2	55.6	52.1	48.3	44.8	41.0	37.5	34.0	30.6	27.4	24.2	21.1	18.5	16.3	14.0	11.8	9.5	7.8	6.2	5.0
30.0%	8.8	6.2	4.2	2.9	2.0	1.3	0.8	0.5	0.3	0.2	0.1	0	0	0	0	0	0	0	0	0	0
40.0%	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45.5%	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
51.0%	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
61.0%	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
66.5%	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
72.5%	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
83.0%	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
94.0%	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
100.0%	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N_{h1} hours	625	602	580	560	542	524	508	492	478	464	451	439	428	417	406	396	387	378	369	361	353
N_{h2} hours	625	602	580	560	542	524	508	492	478	464	451	439	428	417	406	396	387	378	369	361	353

R – plant size ratio; N_{h1} – number of load hours per year;

N_{h2} – N_{h1} plus the load hours that exceed the maximum capacity

Table A4: Mixed heating profiles - PAS 67 Table 2 **Regime 4**

R ratio	0.5	0.6	0.7	0.8	0.9	1	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2	2.1	2.2	2.3	2.4	2.5
Part-load	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days
2.5%	26.9	27.9	29.3	30.7	32.3	33.8	35.6	37.5	39.4	41.1	43.0	44.9	46.8	48.7	50.5	52.4	54.4	56.3	58.2	60.2	62.3
10.0%	16.1	20.7	25.1	29.4	34.1	38.8	44.0	48.3	52.5	57.1	62.3	67.6	72.8	77.9	83.2	88.1	92.8	96.8	100.5	104.2	107.3
20.0%	19.3	23.9	29.4	33.8	38.9	44.7	49.4	54.8	59.3	62.4	64.3	64.6	65.2	66.2	66.0	65.6	65.1	64.6	64.1	62.4	60.9
30.0%	21.4	25.7	31.1	37.4	41.9	43.4	43.7	42.7	43.0	43.1	42.6	42.8	41.2	38.4	36.0	32.6	28.3	23.9	19.3	15.9	12.4
40.0%	21.5	28.3	32.2	33.0	31.5	32.1	32.3	32.3	30.3	27.4	24.7	20.0	15.4	11.1	6.9	4.1	2.5	1.4	0.8	0.4	0.2
45.5%	2.5	2.4	2.1	1.7	1.5	2.8	2.5	2.2	1.6	1.6	0.8	0.5	0.4	0.2	0.1	0.1	0	0	0	0	0
51.0%	7.2	11.6	15.2	15.5	18.3	16.6	16.2	15.0	12.4	8.3	4.6	2.3	1.1	0.5	0.2	0	0	0	0	0	0
61.0%	23.5	23.8	22.0	23.3	21.5	18.3	14.3	8.6	4.1	1.9	0.8	0.3	0	0	0	0	0	0	0	0	0
66.5%	2.2	1.7	1.6	1.2	1.0	1.5	0.8	0.1	0.1	0.1	0	0	0	0	0	0	0	0	0	0	0
72.5%	2.2	5.0	7.6	8.2	8.1	6.5	2.8	1.2	0.4	0.1	0	0	0	0	0	0	0	0	0	0	0
83.0%	19.8	18.6	17.7	14.6	10.2	3.7	1.2	0.3	0	0	0	0	0	0	0	0	0	0	0	0	0
94.0%	19.1	20.2	15.7	10.7	3.2	0.9	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
100.0%	61.4	33.1	14.0	3.3	0.7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N_{h1} hours	3339	2888	2492	2159	1891	1676	1507	1372	1260	1166	1086	1017	956	903	855	812	774	738	706	677	650
N_{h2} hours	3722	3020	2526	2165	1891	1676	1507	1372	1260	1166	1086	1017	956	903	855	812	774	738	706	677	650
N_c days	100	75	54	36	22	11	4	2	0	0	0	0	0	0	0	0	0	0	0	0	0
N_u days	32	36	38	39	40	36	31	23	16	10	5	2	1	1	0	0	0	0	0	0	0
X factor	1.146	1.115	1.088	1.066	1.048	1.032	1.021	1.014	1.009	1.005	1.003	1.001	1.001	1	1	1	1	1	1	1	1

R ratio	2.6	2.7	2.8	2.9	3	3.1	3.2	3.3	3.4	3.5	3.6	3.7	3.8	3.9	4	4.1	4.2	4.3	4.4	4.5	4.6 or more
Part-load	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days
2.5%	64.4	66.4	68.3	70.2	72.6	74.9	77.3	79.6	81.7	83.7	85.8	87.9	89.8	91.9	93.9	96.1	98.3	100.4	102.8	105.3	107.7
10.0%	109.7	112.2	114.9	117.8	120.2	122.1	123.9	125.4	127.0	128.4	129.7	130.9	132.1	132.6	132.8	132.9	132.9	133.1	132.4	131.6	130.3
20.0%	60.0	58.2	55.6	52.1	48.3	44.8	41.0	37.5	34.0	30.6	27.4	24.2	21.1	18.5	16.3	14.0	11.8	9.5	7.8	6.2	5.0
30.0%	8.8	6.2	4.2	2.9	2.0	1.3	0.8	0.5	0.3	0.2	0.1	0	0	0	0	0	0	0	0	0	0
40.0%	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45.5%	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
51.0%	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
61.0%	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
66.5%	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
72.5%	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
83.0%	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
94.0%	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
100.0%	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N_{h1} hours	625	602	580	560	542	524	508	492	478	464	451	439	428	417	406	396	387	378	369	361	353
N_{h2} hours	625	602	580	560	542	524	508	492	478	464	451	439	428	417	406	396	387	378	369	361	353
N_c days	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N_u days	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
X factor	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Key overleaf

Key for Table A4

N_{h1} – number of load hours per year

R – plant size ratio

N_{h2} – number of load hours without a restricted maximum capacity

N_C – number of days in continuous mode

N_U – number of days in unimodal mode

X – extended heating factor

APPENDIX B: SAP Parameters

This appendix lists the data requirements for SAP 2005, Ref. [1].

The plant size ratio, R, is estimated from the design heat loss and the nominal heat output of the package. It is used to interpolate intermediate results between the nearest two from a set of four applicable to a plant size ratio, R, of 0.5, 1, 1.5 and 4. The intermediate parameters are tabulated below.

Table B1 – SAP Parameters

Description	Symbol	Units	Section
1. Plant size ratio for which data apply	R	none	2.5, 2.13
2. Annual heat generated for space heating	$Heat_{sp}$	kWh_h pa	2.13.1
3. Annual heat generated for water heating, if any	$Heat_{DHW}$	kWh_h pa	2.13.2
4. Annual auxiliary heat requirement	$Heat_{aux}$	kWh_h pa	2.13.3
5. Heating season thermal efficiency	$\eta_{thermal,hs}$	%	2.13.4
6. Summer season thermal efficiency	$\eta_{thermal,sum}$	%	2.13.5
7. The net electricity consumed during the heating season (negative if generation exceeds consumption)	$Elec_{conSAP,hs}$	kWh_e pa	2.13.6
8. The net electricity consumed during the summer season (negative if generation exceeds consumption)	$Elec_{conSAP,sum}$	kWh_e pa	2.13.7
9. Number of days operating for 16 hours instead 9	$N_{16,9}$	Days	Table 7, 2.13.8
10. Number of days operating for 24 hours instead 9	$N_{24,9}$	Days	Table 8, 2.13.9
11. Number of days operating for 24 hours instead 16	$N_{24,16}$	Days	Table 9, 2.13.10

See SAP 2005 Appendix N for further details.

APPENDIX C: Additional DHW tests

These calculations are required for regular packages only and involve adjustments to the 24-hour hot water tests and the additional calibration tests are used to estimate a) the standby heat loss from the cylinder and primary pipework and b) the change in the energy content of the cylinder over 24-hours.

C1 Change in the energy content of water in the cylinder

During the 24-hour domestic hot water test of regular packages (RegPk) adjustments to the heat generated are necessary because of the possible changes in the energy content of the water in the external cylinder during the test.

The energy content of the cylinder is measured at seven points vertically on the side of the cylinder, space as shown in table C1. The spacing was chosen deliberately to reduce the measurement error (Ref. [12]).

Table C1 Cylinder temperature at start and end of 24-hour test

	A# Start	B# End	C Weighting fraction†	(B-A) x C (End - Start) x weighting
	°C	°C		K
Cylinder surface temperature top			0.14	
Cylinder surface temperature height 650mm			0.28	
Cylinder surface temperature height 400mm			0.19	
Cylinder surface temperature height 300mm			0.11	
Cylinder surface temperature height 200mm			0.11	
Cylinder surface temperature height 100mm			0.11	
Cylinder surface base			0.06	
Change in mean weighted cylinder temperature				Sum

† Different thermocouple spacing and cylinder size will require different weighting factors.

Columns A and B are from the PAS 67 results table 4, columns F and G.

The change in the energy content, Q_{hwre}, of the water in the cylinder is calculated according to equation C1; making use the summation in table C1 and taking care to note the sign.

$$Q_{hwres} \text{ (in kWh/day)} = Sum_{table\ C1} x\ 4.18\ x\ 120 \div 3600 \qquad \text{C1}$$

120 is volume of the cylinder primary plus secondary water

4.18 is the specific heat of water at 20°C in kJ/kg/K

The density of water is taken as precisely 1 kg/litre and 3600 converts to kWh.

If the average cylinder temperature at the end of the test is colder than start, then a negative adjustment is necessary because heat is extracted from the cylinder during the test which otherwise would not be accounted for. The reverse is also true.

C2 Cylinder and primary pipe heat loss

The cylinder and primary pipe heat loss during the 24-hour tapping test cannot be measured accuracy due to the transient small temperature changes. Instead they estimated using the average cylinder and known steady heat loss for a nominal 25K and 45K rise above ambient obtained during two calibration tests.

First using least squared linear regression; calculate the gradient of primary pipe power and temperature calibration tests from C2. This assumes the constant is zero, that is, no electrical power is required to keep the pipes at the same temperature of its surrounding.

$$m_{pp} = \frac{(\frac{T_{F45}}{2} + \frac{T_{R45}}{2} - T_{amb,pp45}) \times P_{pp45} + (\frac{T_{F25}}{2} + \frac{T_{R25}}{2} - T_{amb,pp25}) \times P_{pp25}}{(\frac{T_{F45}}{2} + \frac{T_{R45}}{2} - T_{amb,pp45})^2 + (\frac{T_{F25}}{2} + \frac{T_{R25}}{2} - T_{amb,pp25})^2} \qquad \text{C2}$$

The measurements required are defined in table C2.

Table C2 Primary pipe calibration test data

	45K calibration test	25K calibration test
Primary flow temperature °C	T_{F45}	T_{F25}
Primary return temperature °C	T_{R45}	T_{R25}
Ambient temperature °C	$T_{amb,pp45}$	$T_{amb,pp25}$
Power to keep primary pipes warm W	P_{pp45}	P_{pp25}

Secondly calculate the gradient for cylinder and primary pipe calibration test using C3. The symbols are defined in table C3.

$$m_{pc} = \frac{(Sum_{45} - T_{amb,pc45}) \times P_{pc45} + (Sum_{25} - T_{amb,pc25}) \times P_{pc25}}{(Sum_{45} - T_{amb,pc45})^2 + (Sum_{25} - T_{amb,pc25})^2} \qquad \text{C3}$$

Table C3 Cylinder and primary pipe calibration test data

	A	B	C	A x C	B x C
	45K calibration test	25K calibration test	Weighting fraction	Weighted Temperature for 45K	Weighted Temperature for 45K
Cylinder surface top °C			0.14		
Cylinder surface height 650mm °C			0.28		
Cylinder surface height 400mm °C			0.19		
Cylinder surface height 300mm °C			0.11		
Cylinder surface height 200mm °C			0.11		
Cylinder surface height 100mm °C			0.11		
Cylinder surface base °C			0.06		
Weighted mean cylinder temperature°C				Sum_{45}	Sum_{25}
Ambient temperature °C	$T_{amb,pc45}$	$T_{amb,pc25}$			
Power to keep cylinder and pipes warm W	P_{pc45}	P_{pc25}			

Thirdly calculate difference in the gradients to give an estimate of the cylinder contribution.

$$m_{cyl} = m_{pc} - m_{pp} \qquad \text{C4}$$

Finally calculate the estimated heat loss during the 24-hour test using C5, with the measurements required defined in table C4

$$Q_{hwstbylab} = m_{cyl} \times (Sum_{\text{table C3}} - T_{amb}) + m_{pp} \times (0.5 \times T_F + 0.5 \times T_R - T_{amb}) \qquad \text{C5}$$

Table C4: DHW 24 test data

	A Temperature	B Weighting fraction	A x C
	°C		°C
Cylinder surface top °C		0.14	
Cylinder surface height 650mm °C		0.28	
Cylinder surface height 400mm °C		0.19	
Cylinder surface height 300mm °C		0.11	
Cylinder surface height 200mm °C		0.11	
Cylinder surface height 100mm °C		0.11	
Cylinder surface base °C		0.06	
Ambient temperature	T_{amb}		
Primary flow temperature	T_F		
Primary return temperature	T_R		
Weighted mean cylinder temperature			Sum

Although the weighting factors are difference for volume and area dependent variables the difference was found to be tiny so only one set of weighting factors is used for simplicity (Ref. [12]).

APPENDIX D: Nomenclature

Table D1: Alphabetical list of symbols and description

Symbol	Unit	Description
Ce	$kgCO_2$/year	Carbon dioxide emissions associated with the electricity consumed (or generated if negative) by the µ-cogen package
Cf	$kgCO_2$/year	Carbon dioxide emission associated with the µ-cogen package
CIF_{fuel}	$kgCO_2$/kWh	Carbon intensity factor for natural gas, LPG or Oil
$CIF_{electricity}$	$kgCO_2$/kWh	Carbon intensity factor for electricity imported from the public supply
dhl	kW	Design heat loss
E_L	kWh/year	Electricity generated minus that consumed during the 24 hour laboratory tests at the nearest load below load x% of the maximum daily load
$Elec_{aux}$	kWh/year	Annual electricity consumed by devices (eg central heating pump) used for heating and hot water but not part of the µ-cogen package.
$Elec_{conHP}$	kWh/year	Annual electricity consumed minus that produced (assumes $Heat_{hw}$ and HW_{aux} supplied by electrical heating)
$Elec_{conSAP,hs}$	kWh/year	Electricity consumed minus that produced (excludes any $Heat_{hw}$ and HW_{aux}) during the heating season
$Elec_{conSAP,sum}$	kWh/year	Annual electricity consumed minus that produced (excludes any $Heat_{hw}$ and HW_{aux}) during the heating season.
$Elec_{hs}$	kWh/year	Electricity generated minus that consumed in the heating season
$Elec_{sum}$	kWh/year	Electricity generated minus that consumed in the summer season
$E_{si,j}$	kWh/year	Electricity generated minus that consumed during the 24 hour laboratory tests at the supplementary loads 20, 40…90% for mode j.
E_T	kWh/year	Sum of the product of electricity generated and the number of days at a given load
E_U	kWh/year	Electricity generated minus that consumed during the 24 hour laboratory tests at the nearest load above load x% of the maximum daily load
E_w	kWh/day	Electricity generated minus that consumed during the 24 hour hot water laboratory tests
E_x	kWh/day	Electricity generated minus that consumed during the 24 hour laboratory tests at x% of the maximum daily load

Table D1: Alphabetical list of symbols and description		
Symbol	Unit	Description
$E_{x2,}$	kWh/day	Electricity generated minus that consumed during the 24 hour laboratory tests at 30% of the maximum daily load
$E_{x2,}$	kWh/day	Electricity generated minus that consumed during the 24 hour laboratory tests at 30% of the maximum daily load
$E_{x2,c}$	kWh/day	Estimated electricity generated minus that consumed during continuous operation at a part-load of x2
E_0	KWh/day	Electricity generated minus that consumed during the 24 hour standby loss laboratory tests
$E_{45.5}$	kWh/day	Estimated electricity generated minus that consumed a part-load of 45.5% of the daily maximum
$E_{45.5,b}$	kWh/day	Estimated electricity generated minus that consumed during bimodal operation at a part-load of 45.5% of the daily maximum
$E_{66.5}$	kWh/day	Estimated electricity generated minus that consumed at a part-load of 66.5% of daily maximum
$E_{66.5,u}$	kWh/day	Estimated electricity generated minus that consumed during unimodal operation at a part-load of 66.5% of daily maximum
E_{100}	kWh/day	Electricity generated minus that consumed during the 24 hour laboratory tests at full load
F_L	kWh/year	Fuel (gross) consumed during the 24 hour laboratory tests at the nearest load below load x% of the maximum daily load
$F_{si,j}$	kWh/year	Fuel (gross) consumed during the 24 hour laboratory tests at the supplementary loads 20, 40…90% for mode j
F_T	KWh	Sum of the product of fuel consumed and the number of days at a given load
F_u	kWh/day	Fuel (gross) consumed during the 24 hour laboratory tests at the nearest load above load x% of the maximum daily load
$Fuel_{con}$	kWh/year	Annual fuel consumed
$Fuel_{hs}$	kWh/year	Fuel consumed in the heating season
$Fuel_{hs,storloss}$	kWh/year	Fuel consumed in the heating season minus that assigned to keep an internal hot water store hot.
$Fuel_{sum}$	kWh/year	Fuel consumed in the summer season
F_w	kWh/day	Fuel (gross) consumed during the 24 hour hot water laboratory tests
F_x	kWh/year	Fuel (gross) consumed during the 24 hour laboratory tests at x% of the maximum daily load
F_{x1}	kWh/year	Fuel (gross) consumed during the 24 hour laboratory tests at 10% of the maximum daily load
F_{x2}	kWh/year	Fuel (gross) consumed during the 24 hour laboratory tests at 30% of the maximum daily load

Table D1: Alphabetical list of symbols and description		
Symbol	Unit	Description
$F_{x2,c}$	kWh/year	Estimated fuel (gross) consumed during continuous operation at a part-load x2.
F_0	kWh/year	Fuel (gross) consumed during the 24 hour standby loss laboratory tests
$F_{45.5}$	kWh/year	Estimated fuel (gross) consumed during at a part-load of 45.5%
$F_{45.5}$	kWh/year	Estimated fuel (gross) consumed during bimodal operation at a part-load of 45.5%
$F_{66.5}$	kWh/year	Estimated fuel (gross) consumed at a part-load of 66.5%
$F_{66.5,u}$	kWh/year	Estimated fuel (gross) consumed during unimodal operation at a part-load of 66.5%
F_{100}	kWh/year	Fuel (gross) consumed during the 24 hour laboratory tests at full load
$Heat_{anx}$	kWh/year	Auxiliary heating required because the package cannot provide sufficient space heating.
$Heat_{DHW}$	kWh/year	Annual heat generated for hot water
$Heat_{genHP}$	kWh/year	Annual heat generated for heating and hot water (if any) required for HPER purposes (includes heat lost subtracted form an external cylinder.
$Heat_{hs,hw}$	kWh/year	Energy content of the hot water drawn in the heating season
$Heat_{hwstbylab}$	kWh/year	Daily heat generated in the laboratory due to an external indirect cylinder (BS 117 litre) and insulated primary pipes; multiplied by 365 days/year (see table 1, item 13)
$Heat_{sp}$	kWh/year	Annual heat generated for space heating
$Heat_{sp,unres}$	kWh/year	Annual heat generated for space heating if heat output were not restricted.
$Heat_{sum}$	kWh/year	Energy content of the hot water drawn in the summer season
HW_{aux}	kWh/year	Auxiliary hot water heating required because the package cannot provide sufficient hot water for each day of the year
l_i	None	Part load profile for day i, expressed as fraction of maximum daily load.
$Load_{space}$	kW	For day i, the space heating part-load
$l_{i,space}$		Part load profile for day i, expressed as fraction of maximum daily load due to space heating
m_{cyl}	W/°C	Power verses temperature gradient for heat loss from cylinder
m_{pc}	W/°C	Power verses temperature gradient for heat loss from cylinder and primary pipes
m_{pp}	W/°C	Power verses temperature gradient for heat loss from primary pipes only

Table D1: Alphabetical list of symbols and description

Symbol	Unit	Description
N_c	Days	Number of days the package would operate continuously
N_{occ}	occupants	Number of occupants
N_u	Days	Number of days a package operates in unimodal operation
N_{h1}	hours/year	The number of hours a package would operate if it operated at full load through the year.
N_{h2}	hours/year	The number of the hours a package would operate at full load including the hours that exceed the maximum capacity
$N_{h2,11}$	hours/year	N_{h2} for bimodal heating
$N_{16,9}$	days/year	Number of days package operates at 16 hours instead of 9 hours
$N_{24,9}$	days/year	Number of days package operates at 24 hours instead of 9 hours
$PHER$	kg CO_2/kWh	Plant heating emission rate
P_{nom}	kW	Nominal heat output of package
Q_{100}	kWh/day	Heat output during full load continuous 24 hour test
P_{pc25}	Watts	Electrical power during the primary pipe and cylinder DHW calibration test for 25K rise above ambient.
P_{pc45}	Watts	Electrical power during the primary pipe and cylinder DHW calibration test for 45K rise above ambient.
P_{pp25}	Watts	Electrical power during the primary pipe only DHW calibration test for 25K rise above ambient.
P_{pp45}	Watts	Electrical power during the primary pipe only DHW calibration test for 45K rise above ambient.
$Q_{hwstbylab}$	kWh/year	Daily heat generated in the laboratory due to an external indirect cylinder (BS 117 litre) and insulated primary pipes (see table 1, item 13)
Q_{hwres}	kWh/day	Heat gain or lost due changes in the temperature of stored hot water during a domestic hot water test.
$Q_{si,j}$	kWh/day	Heat output during supplementary loads 20, 30, 40 ..90% for mode j.
Q_{x1}	kWh/day	Heat output during nominal 10% load test
Q_{x2}	kWh/day	Heat output during nominal 30% load test
Q_w	kWh/day	Heat output during domestic hot water test
R	None	Plant size ratio
S_f	None	Heating load of an undersized package expressed as a fraction of the load if the package could meet the load.
SL	kW/^{o}C	Specific heat loss of dwelling
Sum_{table}	Varies	The summation of a quantity shown by the indicated in the subscript that usually refers to a table.

Table D1: Alphabetical list of symbols and description

Symbol	Unit	Description
T_{amb}	^{o}C	Laboratory temperature during DHW 24 hour tapping test
$T_{amb,pc25}$	^{o}C	Laboratory temperature during DHW cylinder and pipe calibration test at 25K rise above ambient
$T_{amb,pc45}$	^{o}C	Laboratory temperature during DHW cylinder and pipe calibration at 45K rise above ambient
$T_{amb,pp25}$	^{o}C	Laboratory temperature during DHW pipe calibration at 25K rise above ambient
$T_{amb,pp45}$	^{o}C	Laboratory temperature during DHW pipe calibration at 45K rise above ambient
T_{ave16}	^{o}C	Mean internal temperature during unimodal operation
T_{ave77}	^{o}C	Mean internal temperature during SAP heating times
$T_{aveoff16}$	^{o}C	Mean internal temperature during off-period in unimodal operation
$T_{aveoff77}$	^{o}C	Mean internal temperature during off-period of SAP heating times
T_b	^{o}C	Base temperature
T_{id}	^{o}C	Inside design temperature
T_{od}	^{o}C	Outside design temperature
T_F	^{o}C	Primary flow temperature during the 24 hour tapping test
T_{F25}	^{o}C	Primary flow temperature during the DHW pipe only calibration test at nominal rise of 25K above ambient.
T_{F45}	^{o}C	Primary flow temperature during the DHW pipe only calibration test at nominal rise of 45K above ambient.
T_R	^{o}C	Primary return temperature during the 24 hour tapping test
T_{R25}	^{o}C	Primary return temperature during the DHW pipe only calibration test at nominal rise of 25K above ambient.
T_{R45}	^{o}C	Primary return temperature during the DHW pipe only calibration test at nominal rise of 45K above ambient.
T_{oi}	^{o}C	Mean outside temperature for day i
X	None	Extended heating factor – annual heating load required to keep a property warm divided by the annual load required to keep the property warm for 11 hours/day
x	%	Part load expressed as percentage of 24 x Q_{100}
x_L	%	The next part load condition below load x%
x_U	%	The next part load condition above load x%
$x1$	%	Part load during the nominal 10% load test
$x2$	%	Part load during the nominal 30% load test

Table D1: Alphabetical list of symbols and description		
Symbol	Unit	Description
$\eta_{thermal,hs}$	none	Thermal efficiency during the heating season
$\eta_{thermal,sum}$	none	Thermal efficiency during the summer season