Technical Papers supporting SAP 2009

Boiler efficiency for community heating in SAP

Reference no.	STP09/B06
Date last amended	26 March 2009
Date originated	28 May 2008
Author(s)	John Hayton and Alan Shiret, BRE

Summary

For boilers serving more than one dwelling, or community heating boilers, there is not a precise definition of the “manufacturer’s declared efficiency” in the Government’s Standard Assessment Procedure (SAP) leading to possible confusion, ambiguity and misuse.

There is a well documented procedure for boilers serving single dwellings, known as SEDBUK (See appendix D, SAP), which essentially equates the domestic seasonal efficiency to the average of the test full and part load efficiency minus a loss coefficient.

This report firstly describes some definitions of seasonal boiler heat efficiencies in use, the approach in SAP and test standards. Secondly, it examines possible new approaches including adopting a seasonal efficiency defined in the Non-domestic heating, cooling and ventilation compliance guide (NDHCVCG) and extending the SEDBUK method to include community boilers.

The latter approach is favoured as an analysis of design load factors, load diversity, and boiler and system modulation, all pertinent to community heating, suggests that the impact on the loss coefficients is minimal.

It is therefore recommended that the SEDBUK procedure is extended to community systems without alterations to SEDBUK equations. This will mean that conversion to gross efficiencies and capped test values will be automatically incorporated. An additional step is needed for multiple boiler applications to derive the efficiency at 30% and 100% of the system output. This additional step is described.

The analysis excludes appraising the effect on efficiency of heating controls. Further work is recommended to examine the effect of the complex heating controls employed by community systems.

Finally the occurrence of two different community heating efficiencies in SAP is noted and it suggested that the one used for calculating carbon dioxide emissions is retained and the one used for the rating calculation is renamed to avoid confusion.

Contents

1 Introduction

The Government's Standard Assessment Procedure (SAP)[1] documents a method to determine the seasonal heating efficiency (or SEDBUK) for boilers serving single dwellings. For energy assessors' convenience a boiler database contains entries for most domestic boilers in the UK.

For community boilers (one or more boilers serving more than one dwelling) SAP notes: "if known, use the manufacturer's declared efficiency". This statement is imprecise leading to possible confusion, ambiguity and misuse. The purpose of this report is to recommend ways to avoid this ambiguity.

The remainder of the report starts by describing the seasonal efficiency method used in SAP for individual heating, the treatment of community heating (part 2), the definition of a seasonal efficiency in the Non-domestic heating, cooling and ventilation compliance guide (NDHCVCG)[2] (part 3) and test methods applicable to gas and oil fired boilers (part 4).

To see if it is viable to use the non-domestic seasonal efficiency (from NDHCVCG) in absence of a domestic seasonal efficiency (from SEDBUK) , part 5 compares to the two seasonal values.

Part 6 considers the implications of a domestic seasonal efficiency method for community boilers by examining the possible consequences of design load factors, load diversity, boiler and system modulation range.

Part 7 concludes with recommendations to remove the current imprecision in SAP.

[1] SAP 2005 (2008 update), www.bre.co.uk/sap2005, 8 May 2008
[2] http://www.planningportal.gov.uk/uploads/br/BR_PDF_PTL_NONDOMHEAT.pdf, 8 May 2008

2 Definitions for domestic applications in SAP

2.1 Seasonal efficiency (SEDBUK)

The seasonal efficiency of domestic boilers in the UK (or SEDBUK) is documented in SAP, Appendix D and was introduced in 1998. The SEDBUK is calculated from the Boiler (Efficiency) Directive test results at 100% and 30% load using equations set out in Tables D2.4 and D2.5.

For example, for modulating gas regular boilers the SEDBUK is:

$$\eta_{se} = 0.5 \times (\eta_{100\%} + \eta_{30\%}) - 2 - 4p \quad \text{.......... eqn 1}$$

-2 is the *loss coefficient* that represents the heat loss whilst the boiler is not firing. (The loss coefficient is different for each boiler type/fuel).

p indicates the status of permanent pilot (p=0 if absent and p= 1 if present)

$\eta_{100\%}$ and $\eta_{30\%}$ are the certified boiler test efficiencies at full and part load expressed in percentages of the gross calorific value of the fuel.

Prior to the calculating the SEDBUK, the efficiencies at full and part load are capped (if necessary) to prevent unrealistically high test values being used.

2.2 Boiler Efficiency Database

The Boiler Efficiency Database contains the SEDBUK efficiency of domestic boilers and other details required (for example, status of permanent pilot) by SAP for most boilers (past and present) in the UK.

Boilers with heat outputs over 70kW are not permitted on the boiler efficiency database.

2.3 Community heating

SAP requires a heating efficiency for community heating schemes (one boiler or more boilers serving more than one dwelling) for two purposes:

1) For the SAP energy rating calculations. This efficiency is 100% minus up to 10% depending on control options.

2) For the calculation of carbon dioxide emission ratings. If known, a manufacturer's declared efficiency is used instead of the default efficiency for community boilers of 75% minus up to 10% depending on control option.

Three points are worthy of note concerning the general treatment of community heating in SAP.

i) The efficiency used in the rating calculations (i.e. 1 above) is not a *fuel to heat transfer* efficiency as it is too high, but presumably the impact of actual efficiency is reflected in the fuel supply costs for community heating. This has been confirmed as price used for community heating is the price per unit of heat delivered and not the price per unit of fuel.

ii) Having two community heating efficiencies (100% and 75%) in the SAP is confusing and when the next major revision is undertaken, it is suggested that efficiency used in the emission calculation is retained and the other used for rating purposes is renamed.

iii) The use of the phrase “use the manufacturer's declared efficiency” is vague and open to misuse and error. Options for a precise definition are the focus for the rest of this report.

3 Definitions used in non-domestic applications

The following definitions (3.1 to 3.5) are stated in the "Non-Domestic heating, cooling and ventilation compliance guide" (NDHCVCG)[3] on the minimum performance of boiler systems in non-domestic buildings for the purposes of the Building Regulations.

3.1 Seasonal efficiency

The *seasonal boiler efficiency* for single boiler applications or multiple identical boiler installations in existing dwellings is:

$$\eta_{sbe} = 0.36 \times \eta_{15\%} + 0.45 \times \eta_{30\%} + 0.19 \times \eta_{100\%} \quad \text{.......... eqn 2}$$

where 15% , 30%, 100% are the laboratory test efficiencies expressed in the gross or higher calorific value.

The weighted average load is 36.1% (0.36 x 15% + 0.45 x 30% + 0.19 x 100%).

In the absence of a result at 15% (there is no current requirement to obtain an efficiency value at this load), the value at a load of 15% is equated to the value at 30% load giving:

$$\eta_{sbe} = 0.81 \times \eta_{30\%} + 0.19 \times \eta_{100\%} \quad \text{.......... eqn 3}$$

The weighted average load is 43.3%.

These equations apply to boilers with individual power output of less than 400kW.

For boilers with higher outputs manufacturers declared values should be used.

3.2 Overall seasonal boiler efficiency

For multiple boiler installations of *n* non-identical boilers (i.e. heat output or model differs) in existing dwellings the *overall seasonal boiler efficiency* is defined as:

$$\eta_{osbe} = \frac{\sum_{i=1}^{n} (R_i \times \eta_{i,sbe})}{\sum_{i=1}^{n} R_i} \quad \text{.......... eqn 4}$$

R_i is the rated output of each boiler

$\eta_{i,sbe}$ is the seasonal efficiency of each boiler

Sigma means add the term in brackets for each boiler

[3] http://www.planningportal.gov.uk/uploads/br/BR_PDF_PTL_NONDOMHEAT.pdf, 8 May 2008

For single boiler or multiple identical boiler installations the overall seasonal efficiency is the same as the seasonal efficiency.

3.3 Control credits

For purposes of determining Building Regulation Compliance, control credits are assigned to control and system design measures including: boiler not oversized by more 20%, thermostatic radiator valves, room thermostat or sensor, weather compensation and multiple boilers (for full list see, table 7 of the NDHCVCG).

These credits are applied to existing buildings and not to installations in new buildings.

3.4 The effective seasonal boiler efficiency

This is the seasonal efficiency plus any credits added for the system control and design.

3.5 Step method

The definitions in 3.1 to 3.2 are applicable to installations in existing dwellings and single boiler installations in new buildings. For multiple boiler systems installations in new buildings the “three step method” applies which accounts for the different sizes of boilers and still uses the same weighting factors in 3.1.

4 Test methods

The following test standards apply for boilers up to 1000 kW. The key point is that the basic test conditions at full and part-load in each standard are the same and so the basic methodology does not need to change when a boiler output of 70kW is exceeded.

The test standards for:

a) Gas boilers up 70kW:

BS EN 677 :1998 Gas-fired central heating boilers. Specific requirements for condensing boilers with a nominal heat input not exceeding 70 kW ; deals with the special requirements for condensing boilers and the correct test conditions (including a boiler return temperature of 30°C as required by the BED). Other requirements are given in BS EN 297 (Type B), BS EN 483 (Type C), BS EN 625 (Combination boilers).

b) Gas boilers from 70 - 1000kW:

BS EN 15417:2006 Gas-fired central heating boilers. Specific requirements for condensing boilers with a nominal heat input greater than 70 kW but not exceeding 1000 kW ; deals with the special requirements for condensing boilers and the correct test conditions (including a boiler return temperature of 30°C as required by the BED). Other requirements are given in

- EN 656:1999, Gas-fired central heating boilers Type B boilers of nominal heat input exceeding 70 kW, but not exceeding 300 kW
- EN 13836:2006, Gas-fired central heating boilers Type B boilers of nominal heat input exceeding 300 kW, but not exceeding 1 000 kW
- prEN 15420:2006, Gas-fired central heating boilers Type C boilers of nominal heat input exceeding 70 kW, but not exceeding 1 000 kW

Note BS EN 303 (parts 1-6) also deal with gas boilers with a separate boiler body. The test method is the same as given in the above standards. BS EN 303-3:1999 deals with boilers with heat outputs above 1000kW.

c) Oil boilers

BS EN 304:1992 (as amended) Heating boilers, Test code for heating boilers for atomizing oil burners ; Deals with both condensing and non-condensing boilers of any heat output.

d) Very large boilers

Where it is not practical to determine the efficiency of a boiler in the laboratory due to size or thermal output, manufacturers may use the procedure for assessing thermal performance of boilers as set out in BS845:part 1:1987.

5 Comparison of seasonal efficiencies

To see if it is viable to use the non-domestic seasonal efficiency in absence of SEDBUK, part 5 compares to the two seasonal values.

By subtracting equation 1 from equation 3, the difference between the domestic (based on SEDBUK) and non-domestic seasonal efficiency (using the non-domestic heating, cooling and ventilation compliance guide) for modulating gas regular boilers (the most likely case in practice) is:

$$\eta_{sbe} - \eta_{se} = 0.31 \times (\eta_{30\%} - \eta_{100\%}) + 2 + 4p \qquad \text{.......................... eqn 5}$$

The differences for modulating gas regular boilers without a permanent pilot are tabled below for a range of full and part load efficiencies.

Table 1: Modulating gas regular boilers season efficiencies (% gross) differences

Part load		Full load				
	Net	*88.8%*	*91.6%*	*94.3%*	*97.1%*	*99.9%*
Net	Gross	80.0%	82.5%	85.0%	87.5%	90.0%
88.8%	80.0%	2.0%	1.2%	0.4%	-0.3%	-1.1%
91.6%	82.5%	2.8%	2.0%	1.2%	0.4%	-0.3%
94.3%	85.0%	3.6%	2.8%	2.0%	1.2%	0.4%
97.1%	87.5%	4.3%	3.6%	2.8%	2.0%	1.2%
99.9%	90.0%	5.1%	4.3%	3.6%	2.8%	2.0%
102.7%	92.5%		5.1%	4.3%	3.6%	2.8%
105.4%	95.0%			5.1%	4.3%	3.6%
108.2%	97.5%				5.1%	4.3%

Note
Positive values mean the domestic value is lower than the non-domestic value
The values three or four cells below the leading diagonal (shaded) correspond to condensing boilers.
Non condensing boilers correspond to values just above the leading diagonal.

Usually for condensing boilers, the part load efficiency, measured at a boiler return of 30°C, is much higher than the full load efficiency because it is measured at a higher return of 60°C. The part load efficiency is larger than typical values in practice and full load efficiency is smaller. The figure in practice is expected to lie somewhere near the middle.

The non-domestic seasonal estimate has a larger weighting factor applied to the part load (0.81 compared to 0.19 in equation 3) than the full load and an implicit loss coefficient of zero, both of which will contribute to an over estimate in the seasonal efficiency. If the non-domestic seasonal efficiency were to be used in place of the SEDBUK, it would over estimate the seasonal value by up to 5% points (see Table 1).

An alternative approach is to extend the SEDBUK to boilers of over 70kW for community heating. A SEDBUK value would be better because it has equal weighting factors and a loss coefficient. This is examined fully in part 6.

6 A SEDBUK for community heating

When SEDBUK was developed in 1998 no equation was devised specifically for community heating systems.

The loss coefficient in the SEDBUK equations represents the heat loss whilst the appliance is not firing when either the room or boiler thermostat is satisfied during the heating times or because it is outside the heating times.

Community systems will almost always be fitted with regular boilers. The value of the loss coefficients for gas[4] on/off regular and modulating regular boilers is -2.5% and -2.0% gross calorific percentage points respectively.

6.1 Design load factor

The value of the loss coefficient depends on the plant size ratio (the boiler heat output divided design heat loss). The higher the ratio the less time the boiler is firing and so the greater the off-losses.

When boilers are installed in community heating a *design load* factor is usually applied. For example, the output for a boiler system serving 20 dwellings is not the sum of the requirements of the individual dwellings but the sum multiplied by a *design load* factor.

This means effectively the plant size ratio for community systems will be smaller than for individual systems. Allowance for heat losses from the distribution pipework will offset this to a certain extent. The following table shows the impact on the loss coefficients due to design load factors by assuming that boiler on-times are increased proportionally and the total cycle time (i.e. on-time plus off-time) is constant.

Table 2: Estimated changes in loss coefficient due to design load factor

Design load factor †	Non-modulating regular (% gross)	Modulating regular (% gross)
100%	-2.5	-2.0
90%	-2.4	-1.9
80%	-2.3	-1.8
70%	-2.2	-1.7
60%	-2.2	-1.6
50%	-2.1	-1.5
40%	-2.0	-1.3
30%	-2.0	-1.2

†As an illustration to aid understanding, a design load factor of 70%, for example, has a plant size ratio that is 30% less than the sum of individual boiler sizes.

[4] The value of loss coefficients for oil boilers is subject to review but the same arguments and findings will apply.

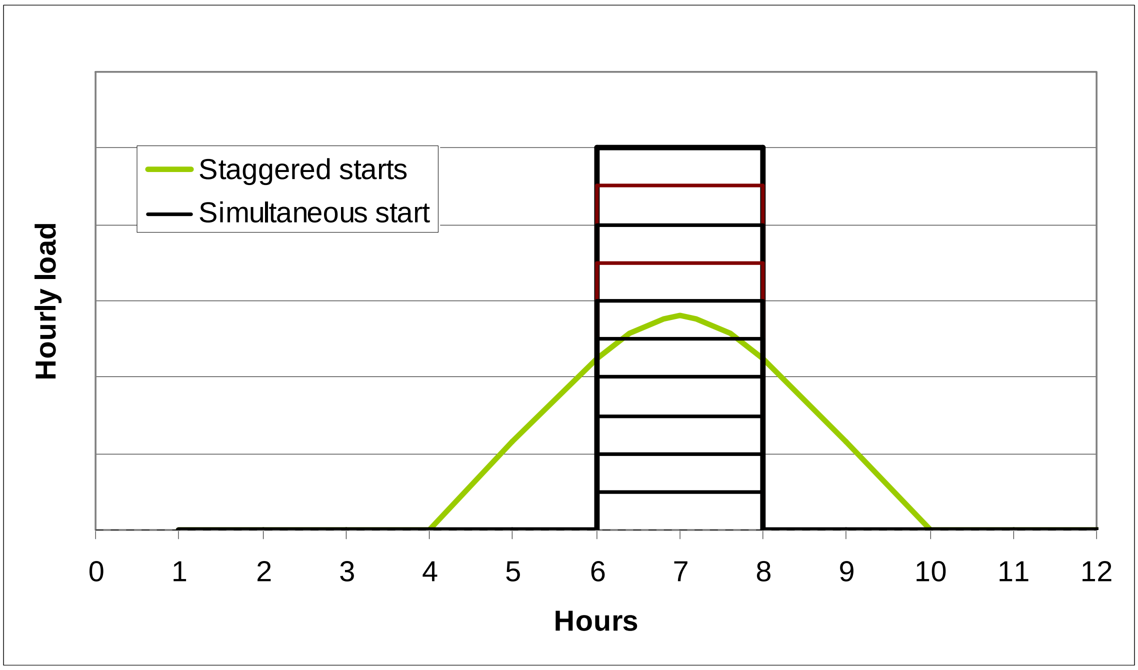
Table 2 shows the effect on the domestic seasonal efficiency is relatively insensitive to the design load factor. Even for a design load factor of 50%, the domestic seasonal efficiency is only reduced by 0.5% gross points.

6.2 Diversity of load

The starting times in different dwellings will not coincide exactly, even if they all deemed to follow the same standard number of hours assumed in SAP, and will result in a diversified load.

By way of explanation consider the figure 1. Firstly, the stacked bar shows the consumption between 6-8am for a community scheme with ten dwellings assuming the heating times in each dwelling are precisely coincident.

Figure 1: Illustration of diversity



Secondly, more realistically the start times will be staggered and result in the load curve shown. The staggered starts results in lower load. In effect, the instead of providing heat over two hours, the boiler provides the same amount over six hours.

The peak load reduction (or peak diversity factor) can be calculated precisely, by assuming the start times follow a truncated normal distribution[5] with a given standard deviation, for example, 1 hour. A standard deviation of 1 hour would mean that all properties would start the two-hour period between 4am and 8am. The peak diversity factor that would result is 56%[6] (that is, the peak load is 56% of the simultaneous total load). The average diversity factor would be lower at 35.1%[7].

A lower load means the off-losses are higher and hence the SEDBUK loss coefficient will be larger in magnitude.

For each heating period in the heating standard defined by SAP, table 3 shows the mean diversity factor for each heating period and the corresponding loss coefficient assuming the

[5] A truncated normal distribution assumes the start times occur +/- 2 standard deviations from the mean start time.

[6] The peak diversity factor is the peak diversified load divided by the simultaneous load. The peak diversified load is the normal distribution value for a mean of 7 hours and standard deviation of 1.5 hours divided by 0.95. 0.95 is the fraction of the cumulative normal distribution value that covers the mean ±2 standard deviations. 1.5 is standard deviation of the spread in possible heating hours which is (2 hours of heating + 4 hours spread in start times) ÷ 4 (i.e. ±2 standard deviations). The simultaneous load is 1 ÷ 2 hours.

[7] The average diversity is the area under the normal curve divided by the spread in heating hours, divided by the average simultaneous load, that is, (0.95 ÷ 6 hours) ÷ (1÷ 2 hours).

start-times are normally distributed two hours either side of mean start time. Also shown are the weekly averages.

Table 3: Diversity and loss coefficient

Heating time/situation	Mean diversity factor	Non-modulating regular coefficient	Modulating regular coefficient
Undiversified	100%	-2.5	-2.0
6-8 (weekdays)	35.1%	-4.34	-4.09
16-23 (weekdays)	67.0%	-2.93	-2.67
6-23 (weekends)	84.2%	-2.65	-2.35
Average (weighted by hours per week)		-3.0	-2.7

Full diversity requires a large number of dwellings, probably over 30 per boiler. Much fewer than this and the load will be lie between the total coincident load and the fully diversified load. Table 3 suggests a change of 0.5% or 0.7% points would be necessary to take into account full diversity achieved in large community schemes. For smaller schemes a smaller change would be necessary.

6.3 Modulation rate

Modern modulating commercial boilers can modulate down to around 20% or even lower. Also community heating systems will almost always include multiple boilers probably with sequence control. Therefore the minimum modulation rate of the whole system will be lower than 20%. For example, a system with two boilers each with a minimum modulation rate of 20% will provide a system that can modulate down to 10%. This would mean the off-losses and hence loss coefficient will be lower.

The loss coefficient calculated for individual systems assumes a modulation rate down to 30%. For a system that can modulate down to 0%, the loss coefficient would be -0.9%[8]; representing the losses at the end of each space heating period and summer season losses.

6.4 Discussion of overall loss coefficient

The effects of design load and system modulation rate on the loss coefficient will counteract the effect of load diversity. It is not clear whether the overall loss coefficient for community heating will be smaller or higher in magnitude than for individual heating but typical differences is likely to less 0.5% and so too small to be of concern.

6.5 Pilot lights

Permanent pilot ignition is rarely used on non domestic boilers (only used on very old units) and so is not an issue for newer installations. For completeness the pilot term should remain in the SEDBUK equation for community heating.

[8] Applying the SEDBUK theory with the assumption that boiler fires continuously during the heating times.

6.6 Multiple boilers

The SEDBUK equations require the average of the test efficiencies at 30% and 100% of the overall system heat output.

For a single boiler system, the system's heat output is the same as the boiler's heat output.

For a multiple boiler installation the overall system efficiency is required and may be calculated as the weighted average of the individual boiler seasonal efficiency thus:

$$\eta_{s,se} = \frac{\sum_{i=1}^{i=n}(R_i \times \eta_{i,se})}{\sum_{i=1}^{i=n}(R_i)} \quad \text{..................... eqn 6}$$

where R_i is the rated output of boiler 1, 2, 3 etc

$\eta_{i,se}$ is the gross SEDBUK efficiency of boiler 1, 2, 3, etc

$\eta_{s,se}$ is the gross SEDBUK efficiency of system

For multiple systems with identical boilers (model, fuel and size), it is noted that $\eta_{1,se} = \eta_{2,se} ...... = \eta_{se}$, so equation 6 simplifies to:

$$\eta_{s,se} = \eta_{se} \quad \text{..................... eqn 7}$$

That is, the seasonal system efficiency is the same as the seasonal boiler efficiency for systems with multiple identical boilers.

6.7 Capping

Laboratory full and part-load efficiency measurements are capped to prevent unrealistically efficiencies being credited. The capping values used for domestic size boilers will apply equally to large boilers as the test temperatures are the same.

6.8 Temperature of distribution system

The higher efficiencies of condensing boilers are only achievable at lower return temperatures. In SEDBUK the average return temperature when firing is assumed to be 45°C; the same as the average of the test temperatures for the full and part load test. This is a key assumption and will be affected by the control system used. Commercial boiler systems in community heating schemes are more likely to use sophisticated controls systems than used in domestic systems. It is suggested that the same average return temperature is used for community heating schemes and consideration made to providing adjustments to take account of more sophisticated controls or poor controls in older systems.

7 Conclusion and recommendations

The non-domestic seasonal efficiency specified in NDHCVC Guide can over estimate the domestic seasonal efficiency by as much as 5% because of the larger weighting factor applied to part load test efficiency (0.81 compared with 0.19) and a loss coefficient of zero. It is also not possible to map simply the non-domestic efficiency to the domestic seasonal efficiency, without prior knowledge of the full and part-load efficiency measurement; making the non-domestic seasonal efficiency inappropriate for use in SAP.

Analysis of load diversity, design load factors and the usually lower modulation rates of commercial boilers show that the loss coefficients derived for community heating boilers are likely to vary only slightly compared to their individual counterparts; varying typically by less than 0.5%. It is therefore recommended that the existing SEDBUK procedure that applies to regular boilers is also applied to boiler systems for community heating. Similar temperatures and load conditions for full and part-load tests are used for all boiler sizes up to 1MW and therefore a seamless and consistent method to estimate seasonal efficiency can be used.

For multiple boiler installations, the efficiency values required for the SEDBUK calculation are those at 30% and 100% of the full system output as defined by equation 6 (see part 6.6)

A decision whether to include boilers above 70kW in the boiler efficiency database needs to be made, possibly introduced as a new community heating category. Community boilers are much less common than individual domestic boilers. Manufacturers' claimed SEDBUK values could be used but this means a much lower level of scrutiny would be applied to boilers over 70KW.

For very large boilers that are impractical to measure in a laboratory with rated output of 1MW or more, manufacturer's declared full and part gross efficiencies must be used in SEDBUK procedure converted to gross terms and capped if necessary.

It also recommended that the problem of two separate "community heating seasonal efficiency" definitions in SAP are resolved by renaming the term used for the rating calculations and retaining the term used for carbon dioxide calculations.

The main recommendation is to replace the imprecise "use the manufacturer's declared efficiency" with "use the Manufacturer's certified SEDBUK value"; calculated according to appendix D. For multiple boilers of non-identical sizes, SEDBUK values or fuels an additional step is required to calculate the seasonal system efficiency from the manufacturers declared boiler SEDBUK efficiencies. (see eqn 6 , part 6.6). For single boiler systems or identical boilers systems the extra step is unnecessary.

The procedure recommended is limited to single fuel systems. Multiple fuel systems will need to account for the how often each fuel is used and is beyond the scope of this present work.

The credits given for controls must not be used in SAP (i.e. the effective seasonal efficiency specified in the NDHCVC Guide), otherwise non sensible efficiencies and inconsistent efficiencies would be used in SAP. Further working looking into the effect of the complex controls employed community systems is recommended.