Changes to the treatment of boilers (gas and oil) in SAP 2009

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Summary

This paper sets out the proposals for changing the treatment of gas (natural gas and LPG) and oil boilers in SAP 2009, referring to supplementary technical papers where necessary. The influence of the Eco-design of Energy Using Products (EuP) Directive is also discussed.

In summary, the changes include:

(a) minor alterations to SEDBUK to deal with anomalies that have arisen (efficiency limits and coefficients for oil boilers re-assessed using the energy balance validation method, and treatment of regular versus combi oil boilers);

(b) reduction of high laboratory test results before calculation of seasonal efficiency, to deal with the upward bias found in results submitted by manufacturers relative to those obtained independently;

(c) replacement of SEDBUK in SAP by separate winter and summer (ie, hot water only) efficiencies, further differentiated for SAP 2009 monthly energy calculations [SEDBUK continues to be used as a minimum standard in the building regulations];

(d) provision for accepting hot water test data for gas combi boilers measured by EN 13203 with schedule no. 2 (a daily hot water demand pattern);

(e) efficiency adjustments for heating controls applied separately to space and water heating;

(f) the influence of heating controls reviewed in accordance with previous assumptions and recently developed typical boiler efficiency characteristics, leading to changes in the efficiency adjustments for boiler interlock, weather compensator, and load compensator controls;

(g) recognition of liquid biofuel as an alternative to mineral oil, if blends are defined with guaranteed characteristics and a suitable labelling scheme for both fuel and installations;

(h) calculation of the efficiency of community heating boilers adapted for greater consistency within SAP, and tabulated distribution loss factors applied only to community heating schemes where the linear heat density is above a threshold.

The details and reasoning are provided within the paper and the further technical references.

Contents

1 Introduction

1.1 The present position

This paper gives proposals for changing the treatment of gas and oil boilers in SAP 2009, referring to other papers where greater technical detail is set out. A number of changes are needed to remove anomalies and bring the treatment of boilers in line with the latest available information, bearing in mind the requirement to deal with all competing heating technologies equitably.

The current edition of SAP (ref 1) uses SEDBUK as the measure of efficiency of gas and oil boilers in dwellings, representing the annual average energy performance of space and water heating over winter and summer conditions. SEDBUK takes results from the full and part-load efficiency tests that boiler manufacturers carry out to comply with the Boiler Efficiency Directive and converts them to a more realistic annual efficiency under typical installed conditions. The SEDBUK method has remained largely unchanged since it was first developed in 1998 (ref 5). SEDBUK also underpins Part L1 of the Building Regulations as a minimum standard for new and replacement boilers.

It is proposed that the single-number SEDBUK is no longer used as an overall seasonal efficiency in SAP, though the steps in the SEDBUK calculation procedure (with minor changes) are retained for differentiating boiler types and fuel.

Community heating boilers are dealt with in SAP by type efficiency, with adjustments, and a more coherent treatment is proposed to avoid an arbitrary difference between individual and community heating in the absence of supporting evidence. In the longer term, the preferred solution is to collect the annual performance data for individual community heating schemes and make it available for SAP assessments.

1.2 The Eco-design of Energy Using Products Directive (EuP)

Boilers and water heaters (including the water heating function of combi boilers) have been identified as products for priority attention under the EuP Directive (see 11) and preparatory studies have been completed. Detailed implementation proposals are being prepared by the European Commission. Whilst it is recognised that the EuP is expected to bring about major changes in the way in which boiler performance is measured and declared, its implementation provisions are not yet known and cannot yet be incorporated in SAP.

To support implementation of the EuP, mathematical models have been developed to estimate product performance when installed in heating systems under a limited range of conditions. The models give a performance index that can be used for setting a minimum legal standard and a rating on an energy label. But a single-number performance index produced by the models for labelling and product comparison will not be usable in SAP if based on incompatible principles and assumptions. For example, the present form of the index gives an approximation to primary energy using a simple power conversion factor, whereas SAP accumulates fuel and power consumption separately to determine carbon emissions. In SAP a detailed assessment of the building fabric is required; the size and construction of the building determines separate figures for heating and hot water demand; and the calculation of carbon emissions to establish regulatory compliance makes use of fuel-specific emission factors.

Nevertheless the EuP models call for energy performance data obtained from EN standard laboratory tests, and the implementation proposals will say which tests have to be done, how many of them, and under what conditions. Such tests can provide relevant data for a future version of SAP as well as for the EuP models. The same test results should be used for both so as to avoid additional testing costs. The test methods for boilers are expected to remain the same as those already in use for the Boiler Efficiency Directive, though under the EuP the range of test conditions for which results are required may be expanded and rationalised.

For the water heating function of gas combi boilers there is a test method defined in EN 13203 that can be used in conjunction with one or more hot water daily demand patterns. It is not yet known if the EuP implementation will require testing to more than one demand pattern, nor whether the choice of demand pattern(s) will be prescribed in relation to plant size or left to the free choice of manufacturers. Nor is it known what test standard will apply to oil combi boilers.

Prospective use of EuP data is discussed further in section 11. Although the future testing regime for boilers and water heaters is not yet known, preparation is being made for it in SAP by separating space heating and water heating efficiencies.

1.3 Reasons for changes in SAP 2009

A full revision of the seasonal efficiency method and assumptions (currently SEDBUK) has not been undertaken because of the impending implementation of the EuP, but reasons for change remain. They include:

(a) Boiler designs have advanced since 1998 and the UK market is now overwhelmingly modulating and condensing.

(b) In 1998 there were no oil condensing and oil combi boilers available for analysis and the SEDBUK equations for them were based on inadequate information.

(c) Evidence collected over a period shows a significant discrepancy between results from boiler efficiency tests carried out independently and those used by boiler manufacturers to obtain entries in the Boiler Efficiency Database. The differences lead to the conclusion that there is a systematic upward bias in results from manufacturers. Although the SEDBUK formulae limit the effect of this by capping, some of the figures submitted for inclusion in the Boiler Efficiency Database for SAP are too high. This conclusion is supported by further evidence from boiler monitoring projects run by the Carbon Trust and Energy Saving Trust.

(d) SAP 2009 will change from annual to monthly calculations, so that the effect of a shorter heating season in well insulated properties can be evaluated more precisely. Newer, well insulated, properties have a much lower ratio of space heating to water heating demand than is currently assumed in SEDBUK. It is therefore better to separate boiler efficiencies applied during the summer and winter seasons, where ‘summer’ means the period in which there is no demand for space heating.

(e) Summer boiler efficiency is applicable to hot water demand only. Separate product test data for the water heating function of combi boilers will enable measured performance to be taken into account, which is preferable to relying on test data for the space heating function alone.

(f) The treatment of heating controls needs to be reviewed so that efficiency adjustments are applied to space heating and hot water separately, in line with the changes above. Also clarification is necessary to ensure that adjustments in Table 4c and 4e of SAP are applied only as intended in the original study on the effect of heating controls used for SAP 2001.

(g) The advent of liquid biofuels (eg, biokerosene) as an alternative to mineral oil should be recognised in SAP, once blends with specific characteristics have been defined.

(h) Greater use of community heating, with or without CHP, calls for a more coherent treatment in SAP.

For SAP 2009, therefore, it is proposed that:

(i) Minor changes to the SEDBUK calculation procedure are made to deal with anomalies that have arisen, as mentioned in (a) and (b) above. These are discussed in sections 3 and 4 of this report and refs 4 and 6.

(ii) The seasonal efficiency of boilers in SAP is reduced by a variable margin to adjust for test results generally too high (see (c) above). This is discussed further in section 5 and a separate paper (ref 3).

(iii) SEDBUK is separated into its components for summer and winter season efficiencies. An additional calculation step is then required to derive monthly space and hot water efficiencies (see (d) above). This is discussed in section 6.

(iv) Provision is made for accepting water heating performance data measured obtained in accordance with EN 13203 (see (e) above), which only applies to gas boilers at present. This involves changing the default store heat loss from combi boilers, and is discussed in section 7. Follow-on changes to Appendix Q applications will also be necessary (see 7.5).

(v) In consequence of (iii) and (iv), the efficiency adjustments for heating controls in Table 4c of SAP are re-arranged for separate application to space and water heating (see section 8).

(vi) The efficiency adjustments for controls in SAP Tables 4c and 4e are altered to ensure that the operational assumptions in the original controls study always apply (see section 8).

(vii) Biofuels as alternatives to mineral oil for oil boilers are recognised, subject to satisfactory definition of blends (see section 9). For recognition of individual biofuel boiler installations, a scheme for labelling will be needed and the range of fuels (if more than one) that can be burned must be known.

(viii) Type efficiency for community heating boilers is replaced by product efficiency (see section 10). In the absence of supporting evidence for a different seasonal efficiency method, this will follow the same calculation procedure as SEDBUK for individual boilers, supplemented by an additional stage to calculate the average efficiency of a bank of boilers. Tabulated distribution loss factors remain unchanged, but are now qualified such that scheme-specific values apply in schemes where the tabulated values may be an under-estimate. The longer term proposal is to collect relevant technical data for each community heating scheme and make it available for SAP assessments from a database.

2 Boiler efficiency in SAP – present assumptions

The current edition of SAP uses SEDBUK (Seasonal Efficiency of Domestic Boilers in the UK) as the measure of efficiency of gas and oil boilers in individual dwellings, representing the annual average energy performance of boilers for space and water heating over winter and summer conditions. SEDBUK is a calculation method that relies on data generated in the laboratory. The calculation is set out in SAP 2005, Appendix D (ref 1).

The rationale for SEDBUK was developed by BG Technology in 1998 (ref 5), with government funding and industry collaboration. This section describes its salient features and in particular the assumptions that need to be reviewed in the light of changes mentioned in the introduction.

The heart of the calculation procedure is a family of equations of the form:

$$E_{ann} = 0.5 \times E_{full} + 0.5 \times E_{part} + C + B - P \quad \text{.......} \quad 1$$

where C is a coefficient that varies for each boiler/fuel type
P is a term related to the presence of a permanent pilot light
B is a term related to the heat loss from any hot water store in a storage combi that is kept hot during the BED efficiency tests. In essence, this term removes the storage heat loss from the BED test efficiencies as these are dealt with elsewhere in SAP.

The coefficient, C, represents the heat loss whilst the boiler is *not firing* because either (a) the room, cylinder or boiler thermostat is not calling for heat or (b) the boiler is off between programmed heating times (or between water heating times in the summer). The heat losses while firing are explicitly included in the efficiency figures.

The impact of the heat loss during the winter and summer was estimated from boiler firing signatures obtained in the field. Critically, the summer water heating fuel demand was assumed to be 9% of the total annual demand for heating and water heating.

Signature data for modulating regular boilers were not available at the time of the development of SEDBUK as very few modulating regular boilers were installed in the field. Signature data for on/off regular boilers were used instead to derive signature data for modulating regular boilers by making the following assumptions:

- A modulation range of 30% to 100%.
- For each on/off cycle recorded from the signature data, when the on-time fraction was 30% or higher, the modulation rate was set equal to it. When the on-time proportion was lower than 30% the modulation rate was set to 30% and a revised on-time proportion calculated.

The formulæ contain the arithmetic average of the measured efficiency at full- and part-load (i.e. $0.5 \times E_{full} + 0.5 \times E_{part}$), which implicitly assume that the average boiler water return temperature when firing in the home is 45°C.

3 Maximum efficiencies

The introduction of an energy balance validation method (ref 4) has enabled an accurate determination of the maximum theoretical full- and part-load efficiency test values.

The maxima calculated for condensing boilers are shown in Table 1.

Table 1: Calculated maximum efficiency (net CV) (condensing boilers)

	Gas	Oil	LPG
Full-load	98.0%	97.9%	98.1%
Part-load	108.0%	103.9%	105.6%

These assumed a standby loss of 0.1% of the full-load output, an excess air fraction of 20%, laboratory humidity of 65% and temperature of 20°C, flue temperature of 33°C (part-load) or 60°C (full-load).

It is proposed that maximum values are rounded to those shown in Table 2 for the purposes of SAP.

Table 2: Proposed permitted maximum efficiency (net CV) (condensing boilers)

	Gas	Oil	LPG
Full-load	98%	98%	98%
Part-load	108%	104%	106%

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4 Coefficient revision (oil boilers)

The coefficients for oil boilers in the SEDBUK equations 201 and 202/203 are 0 for regular and -2.8 for combi boilers.

A separate paper (ref 6) recommends changing 0 to -1.1 in equation 201, retaining -2.8 in equations 202 and 203, and raising the maximum permitted value for net efficiency of non-condensing oil boilers at part-load by 2% (net points) to 93%.

It is proposed that these adjustments are adopted to remove the anomalous treatment of oil boilers.

5 Credibility of test results

Evidence has emerged over a number of years to indicate that boiler efficiencies quoted by manufacturers are upwardly biased relative to those obtained from the same products in independent tests. If independent test and manufacturer test results for the same products were derived from tests conducted equally conscientiously, with due regard for obtaining the most realistic efficiency values, then approximately equal numbers of positive and negative differences between them would be expected. Examination of the differences reveals, however, an overwhelming majority of differences that are negative (ie, those where the independent test results are lower than those obtained by manufacturers).

A statistical analysis (ref 3) has been carried out, bringing together data from nine separate studies covering over 100 boilers tested independently. It concludes that:

- There is very strong evidence to show that the full- and part-load efficiencies of condensing boilers reported by manufacturers are upwardly biased relative to those found in independent tests;
- The upward bias increases with efficiency (ie, is greatest at the highest efficiency figures).

Some upward bias might be expected given the variety of test methods and complexity of the procedure, allowance for adjustments, and the customer-contractor relationship between manufacturers and test laboratories. That may be relatively unimportant when comparing one boiler with another, but any distortion may misinform the Government's energy efficiency policies. Moreover SAP has to evaluate competing heating technologies, and an over-estimation of one type places other types at a disadvantage.

Insufficient data was available to carry out a separate analysis for oil and LPG boilers, although the laboratory tests are carried out on the same rigs and the measurement procedure is essentially the same. It is only the procedure used for measuring the amount of fuel that differs, and in other respects the test procedures and conditions are the same. The standards for measuring the amount of different fuels specify the same overall accuracy, and it is reasonable to conclude that similar result bias occurs for oil and LPG boilers. Neither is there any reason to suppose differences in test bias between the various boiler types (regular boilers, combi boilers and storage combi boilers).

The test procedure for part-load efficiency can differ between on/off and modulating boilers. If boilers can modulate to 30% of the full output, the part-load test is carried out under steady conditions. Boilers that cannot modulate down to 30% are tested either under cyclic conditions (direct method) or by a combination of a steady test and a standby heat loss test (indirect method), so it could be argued that bias may vary with modulation capability. However, it was concluded that there was no significant difference in bias between direct and indirect part-load methods (ref 3). This suggests the main contribution to bias is related to the measurement uncertainty or the boilers tested rather than varying conditions during the test.

The part-load efficiency bias is larger than the full-load bias because the measurement precision is less in the part-load test. There is a lower precision because there is a smaller temperature rise to measure and a lower fuel rate to quantify.

The analysis (ref 3) recommends that an offset that increases with efficiency is fairer than applying a constant offset, and that it is applied before the application of capping and conversion to gross calorific efficiencies. Consequently the proposed changes to SAP 2009 are:

(i) For full-load efficiency (FLE) of 95.5% net or below, no offset is applied.

(ii) For FLE above 95.5%, the offset applied is:

Full-load offset (net) = -0.673 x (FLE(net) - 95.5%) 2

(iii) For part-load efficiency (PLE) of 96.6% net or below, no offset is applied.

(iv) For PLE above 96.6% net, the offset applied is:

Part-load offset (net) = -0.213 x (PLE(net) - 96.6%) 3

These offsets are equally applicable to gas, oil and LPG as they are all essentially carried out using the same equipment, notified test bodies, test methods and precision. They are not applicable to solid fuel testing as the methods used are very different.

There is additional evidence from boiler monitoring projects run by the Carbon Trust and Energy Saving Trust showing that installed efficiency is around 5% lower than current SEDBUK values. The monitoring results are not exactly comparable with SEDBUK because of different conditions (installations, controls, demand patterns) and because some elements of boiler system energy performance are allowed for elsewhere in SAP (not in the SEDBUK figure). However, the monitoring projects give an indication that assumed installed efficiency is too high at present, and after making allowance for these differences a downward adjustment to SAP results in the range 2.3% to 5% is indicated. It is likely that upward bias in boiler test results, as discussed above, is a contributory factor.

6 Separating summer and winter efficiencies

In this context 'summer' means the period in which there is no demand for space heating. The length of the period depends on individual building characteristics and will vary from building to building. There are three reasons to separate summer and winter efficiencies:

1) The proportion of water heating energy required in the summer expressed as a percentage of the annual total for space and water heating varies considerably with building design. Percentages between 5% and 25% are common. As the summer season efficiency and winter season (combined duty) efficiency also varies considerably, maybe by 30 percentage points or so, the overall effect on annual efficiency is significant. For example, if the winter efficiency is 93% and summer efficiency 60%, a summer heating fraction of 5% and 25% will give rise to annual efficiencies of 89.6% and 81.2% respectively[1].

2) The next version of SAP will change to a monthly calculation, making separation of summer and winter season efficiencies desirable.

3) The introduction of a new standard for testing the water heating performance of (gas) combi boilers allows test data to be taken into account. This will give a measure of summer efficiency for combi boilers. The lack of hot water test data in SEDBUK at present is a serious disadvantage.

At present the SEDBUK method combines the winter and summer efficiencies by assuming a summer water heating proportion of 9% over four summer months. It is possible to deconstruct the annual efficiency to derive separate winter (combined space and water heating) and summer (hot water only) efficiencies. The monthly demand for space and water heating is calculated by SAP and it is then possible to used the deconstructed efficiencies to estimate the weighted average space heating efficiency and hot water efficiency separately.

Table 3 shows the coefficients deconstructed. For example, in SEDBUK equation 101, the coefficient, (C = -2.5), is derived from the:

Summer season coefficient x summer proportion + winter season coefficient x winter proportion

= (0.09 x -11.7 + 0.91 x -1.6) = -2.5

[1] As consumption is inversely proportional to the boiler efficiency, the harmonic mean rather than arithmetical mean should be used. The harmonic mean is the reciprocal of the arithmetical mean of the reciprocals.

Table 3: Annual and seasonal coefficients				
Fuel/type	Equation number (SAP Table D2.3)	Coefficient Annual C	Coefficient Winter C_{win}	Coefficient Summer C_{sum}
Natural Gas/LPG				
Regular on/off	101	-2.5	-1.6	-11.7
Regular modulating	102	-2.0	-1.0	-11.7
Instantaneous combi on/off	103	-2.8	-2.0	-11.3
Instantaneous combi modulating	104	-2.1	-1.2	-11.3
Storage combi on/off	105	-2.8	-2.1	-10.0
Storage combi modulating	106	-1.7	-0.9	-10.0
CPSU	107†	-0.761	-0.545	-2.4
Oil				
Regular	201	-1.1‡	0.0	-11.7
Instantaneous combi	202	-2.8	-1.8	-11.3
Storage combi	203	-2.8	-1.9	-10.0

† The present coefficient for a CPSU is equal to 0.761 - 0.222 = 0.539 where 0.222 is an adjustment to remove the store heat loss from the coefficient as the store loss is accounted for elsewhere in SAP.
‡ The value of -1.1 is preferred, as recommended in section 4 and ref. 6, rather than 0 in SAP 2005

Splitting the permanent pilot flame penalty into its seasonal components is not worthwhile as modern boilers do not use permanent pilot ignition. The store heat deduction term is also meaningless in terms of seasonal components as it relates to the BED test results only and not how it performs over a year. It is a means of subtracting the heat loss from the BED efficiencies. Therefore, it is recommended to retain both pilot flame and storage terms unaltered in both the winter and summer expressions.

The planned update to SAP requires the thermal efficiency for hot water production and for central heating to be evaluated separately for each month**.**

It is recommended that the monthly efficiencies are calculated as follows:

1. Calculate the efficiency (E_{win}) in heating season and summer season (E_{sum}) from equation 4 and 5.

$$E_{win} = 0.5 \times E_{full} + 0.5 \times E_{part} + C_{win} - P + B \quad \text{......................................4}$$

$$E_{sum} = 0.5 \times E_{full} + 0.5 \times E_{part} + C_{sum} - P + B \quad \text{...................................5}$$

where

C_{win} and C_{sum} is a coefficient that varies with boiler type and fuel (see Table 3)
E is the gross efficiency indicated by the subscript during the summer season, winter season or during the full- or part-load BED test.
P is the usual term related to the presence of a permanent pilot light
B is the usual term related to the heat loss from any hot water store in a storage combi or CPSU that is kept hot during the BED efficiency tests

For existing entries in the boiler database without a full- and part-load efficiency provided then summer and winter efficiencies can be calculated using 6 and 7.

$$E_{sum} = E_{ann} - C + C_{sum} \quad \text{......6}$$

$$E_{win} = E_{ann} - C + C_{win} \quad \text{......7}$$

where C is the coefficient in the SEDBUK equations (SAP appendix D)

and E_{ann} is the SEDBUK value.

For example, an on/off with a SEDBUK of 65%, has a winter efficiency of 65 -(-2.5)+(-1.6)= 65.9% and summer efficiency of 65 -(-2.5) +(-11.7) = 55.8%

2. Calculate the monthly hot water efficiency using equation 8

$$E_{hw\ (mon)} = 1 \div [(1 - P_{Q_{hw}(mon)}) \div E_{win} + P_{Q_{hw}(mon)} \div E_{sum}] \quad \text{......8}$$

where $P_{Q_{hw}(mon)}$ is the amount of water heating required per month expressed as a proportion of the monthly total of the space and water heating required.

3. Calculate the monthly space heating efficiency using equation 9.

$$E_{sp\ (month)} = E_{win\ (month)} \quad \text{......9}$$

It is proposed that the Boiler Efficiency Database is expanded to include both the winter efficiency and summer efficiency (results of equation 4 and 5, or 6 and 7) as well as the SEDBUK value, which is to be retained mainly for regulatory purposes. Appendix D of SAP will be updated to include the winter and summer equations or coefficients in Table 3. The results of equations 8 and 9 are then used in SAP in conjunction with the heat requirement for space and water heating calculated for each month. The offsets in part 3 are made prior to these equations.

7 Hot water efficiency test data

Having separated efficiency into seasonal components, there is an opportunity to use a direct measurement of the domestic hot water efficiency as determined by EN 13203-2 for combi boilers in place of the calculated efficiency in section 6.

It is important to realise that the simple replacement of the efficiency of heat to primary water (required in SAP) by the DHW efficiency (produced by EN 13203-2) would be incorrect. The amount of energy associated with hot water storage and rejected hot water must be separated from the DHW efficiency so that SAP can calculate any advantageous heat gains from them. These may partly offset the space heating consumption.

A more complicated approach is required to extract from the DHW efficiency the energy lost in any rejected water and any constant loss (independent of water volume) associated with a keep-hot facility or hot water storage. Such a procedure is devised in Appendix A for two situations:

a) Schedule 2 (the hot water demand pattern) only (5.85kWh/day)
b) Schedule 2 and either schedule 3 or 4. (Schedule numbers 5 to 9 apply to daily hot water volumes outside the current SAP range).

7.1 Schedule number 2 result only

The recommended data requirements from schedule number 2 are shown below.

Table 4 Recommended combi boiler data requirements (schedule number 2 results only)

Description	Symbol	Data source	Value and units	Default
Rejected energy proportion	$r_{j,EN2}$	EN 13203-2 schedule 2	(rejected volume ÷ useful volume) × 0.5	Combi loss ÷ (365 × 5.85)
Domestic hot water efficiency	η_{EN2}	EN 13203-2 schedule 2	Useful efficiency (gross)	None
Useful hot water energy	$Q_{dhw,EN2}$	EN 13203-2 schedule 2	Useful hot water energy kWh/day	5.97 ‡
Appliance efficiency - hot water only	η_0	† Estimated as the BED Full-load efficiency 80/60°C	Gross efficiency after deduction (see part 2) and capping.	None

† see discussion below. ‡ this is maximum allowed in the test; ie 2% above 5.85 kWh/day

In SAP two parameters are used to calculate the water heating consumption: a linear term and constant term. These are the appliance efficiency (not the tap efficiency) which is a coefficient of proportionality that links consumption to daily hot water load and a constant term (independent of daily water usage) which represents any storage heat loss, keep-hot service consumption or wasted warm water. Both parameters determine the DHW efficiency measured in the EN 13203 test and need to be uncoupled. Once one is known the other can be calculated, for example as shown in Table 5. The easiest one to estimate is the summer appliance efficiency. For example, for high flow rates the primary water will be substantially cooler, resulting in a higher efficiency. The actual quantity required is the steady efficiency at the average of the flow rates specified in the tapping schedule. For schedule 2, the rates are 50% or less than the typical maximum flow rates of modern combi boilers. So it is likely that the primary circuit temperatures at the lower flow rates will be similar if not higher than those in the BED full-load test (i.e over 60°C).

The plate heat exchangers in modern combi boilers, which transfer heat from the primary water to the domestic water, are extremely effective. As the BED full-load primary water test temperatures are likely to be similar to the temperatures in the hot water test schedule and the plate heat exchangers are extremely effective, the BED full-load test should be a good proxy for the steady state efficiency during hot water operation.

The recommended results for use in SAP are shown below. This Table only applies if schedule 2 results alone are provided. The equations are derived in Appendix A

Table 5 Recommended results for use by SAP (schedule number 2 results only)

Description	SAP 2005	Calculation prior to SAP
Summer appliance efficiency	New monthly value	$E_{sum} = \eta_0$ And use it to calculate the monthly efficiency as outlined in part 4
Storage heat loss	box (46)	Instantaneous combi $= 0$ Storage combi $= [Q_{dhw,EN2} \times \{(\eta_0 \div \eta_{EN2}) - 1 - r_{j,EN2}\} \times 365]$
Additional combi loss	box (49)	Instantaneous combi $= [Q_{dhw,EN2} \times \{(\eta_0 \div \eta_{EN2}) - 1 - r_{j,EN2}\} \times 365]$ $+$ [{box(39)+box (40)} $\times r_{j,EN2}$] Storage combi = [{box(39)+box (40)} $\times r_{j,EN2}$]

7.2 Schedule number 2 plus another schedule

The recommended data requirements are shown below. Tables 6 and 7 only apply if schedule number 2 results plus schedule 3 or 4 results are quoted.

Table 6 Recommended combi boiler data requirements (No 2 with No 3 or No 4 schedule)

Description	Symbol	Data source	Value and units	Default
Rejected energy proportion	$r_{j,EN2}$	EN 13203-2 schedule 2	(rejected volume ÷ useful volume) x 0.5	Combi loss ÷ (365 × 5.85)

Rejected energy proportion	$r_{j,ENx}$	EN 13203-2 schedule x	(rejected volume ÷ useful volume) x 0.5	Combi loss ÷ (365 × 5.85)
Domestic hot water efficiency	η_{EN2}	EN 13203-2 schedule 2	Useful efficiency (gross)	None
Domestic hot water efficiency	η_{ENx}	EN 13203-2 schedule x	Useful efficiency (gross)	None
Useful hot water energy	$Q_{dhw,EN2}$	EN 13203-2 schedule 2	Useful hot water energy kWh/day	1.02 x 5.85
Useful hot water energy	$Q_{dhw,ENx}$	EN 13203-2 schedule x	Useful hot water energy kWh/day	1.02 x value quoted for 3 or 4 schedule

The recommended results for use in SAP are shown in Table 7. These formulæ are derived in Appendix A.

Table 7 Recommended results for use by SAP (No 2 with No 3 or No 4 schedule)		
Description	SAP 2005	Calculation prior to SAP
Hot water appliance efficiency	Summer efficiency	$E_{sum} = \frac{(Q_{dhw,ENx}(1+r_{j,ENx}) - Q_{dhw,EN2}(1+r_{j,EN2}))}{(\frac{Q_{dhw,ENx}}{\eta_{ENx}} - \frac{Q_{dhw,EN2}}{\eta_{EN2}})}$ And use it to calculate the monthly efficiencies (see part 4)
Storage heat loss	box (46)	Instantaneous combi $= 0$ Storage combi $= \frac{\eta_{EN2}(1+r_{j,EN2}) - \eta_{ENx}(1+r_{j,ENx})}{\frac{\eta_{EN2}}{Q_{ENx}} - \frac{\eta_{ENx}}{Q_{EN2}}}$ × 365
Additional combi loss	box (49)	Instantaneous combi $= \frac{\eta_{EN2}(1+r_{j,EN2}) - \eta_{ENx}(1+r_{j,ENx})}{\frac{\eta_{EN2}}{Q_{ENx}} - \frac{\eta_{ENx}}{Q_{EN2}}}$ × 365 $= [\text{box}(39)+\text{box}(40)] \times [r_{j,EN2} + \frac{(V_{j,EN2} - V_{SAP})(r_{j,EN2} - r_{j,ENx})}{(V_{j,EN2} - V_{j,Enx})}]$ Storage combi $= [\text{box}(39)+\text{box}(40)] \times [r_{j,EN2} + \frac{(V_{j,EN2} - V_{SAP})(r_{j,EN2} - r_{j,ENx})}{(V_{j,EN2} - V_{j,Enx})}]$

Note V_{SAP} is the daily hot water usage (including 17.6% distribution loss – see Table 1 of SAP) for the assessment being undertaken.

7.3 Electrical consumption

The EN 13202-2 test procedure records the electricity consumed by the boiler in hot water mode. SAP 2005 adds an amount for the annual use of fans and pumps for both space and water heating operation.

An obvious suggestion is to add the daily electricity consumed multiplied by 365 to the annual electricity assumed in SAP 2005 for fans and pumps, and deduct the amount presumed to be associated with the water heating consumption. The most obvious amount to deduct is the SAP 2005 annual amount multiplied by fuel used for water heating divided by the total fuel used for space and water heating.

Therefore the following formula for electricity consumption is proposed:

Revised annual electricity consumption =

{SAP 2005 annual electricity amount x [(space heating fuel ÷ total fuel for space and water heating)]} + (365 x daily electricity test value)

The amount of heat generated by the electricity is small compared with the central heating and water heating demand, so the potential thermal replacement effect of the electrical gains are also small. Consequently it is recommended that the heat assigned to the pump and fan remains unaltered. The electrical power only becomes an issue because of its relative cost and carbon dioxide emissions compared with other fuels, and they are accounted for in the adjustment above.

7.4 Test results

Data from two gas combi boilers and two oil storage boilers (ref 7) taken from an EN 13203-2[2] test to schedule number 2 are shown in Table 8 to demonstrate the procedure. Values are quoted for the smallest and largest dwellings to show the expected variation with hot water demand.

[2] EN13203 is not intended to apply to oil boilers but was adapted by making changes to fuel measurement.

Table 8 Illustration of the recommended way to used hot water test data in SAP							
Boiler tested	Required laboratory test results				Calculated parameters for use by the new SAP (see Table 5 for details)		
	Rejected energy fraction	Energy in the hot water kWh/day	DHW efficiency % gross	BED Full-load efficiency % gross	Combi Loss kWh/yr $30m^2$ flat	Combi Loss kWh/yr $300m^2$ house	Summer appliance efficiency
Gas instantaneous combi 1 (keep-hot active)	0.03%	5.80	68.1%	88.1%	360	363	88.1%
Gas instantaneous combi 2 (keep-hot active)	0.23%	5.90	72.7%	89.0%	623	624	89.0%
					Storage heat loss kWh/yr		
Oil storage combi 3	0%	5.90	39.0%	93.6%	3020		93.6%
Oil storage combi 4	0%	5.85	37.0%	90.0%	3059		90.0%

Table 9 (below) compares the recommended new values with those in SAP 2005, the differences being shown in brackets. For example, the hot water test combi boiler no. 1 produced 5.80 kWh/day at a gross efficiency of 68.1%. Applying the proposed procedure would mean using a summer appliance efficiency of 88.1% and a constant annual loss of between 360 and 363kWh per year; exact amount depends on floor area of the dwelling. This compares with the current situation where SAP applies 90.2% and a constant loss of between 491 and 900 kWh/yr, for properties of floor area of $30m^2$ and $100m^2$ or more respectively.

Although the summer appliance efficiency is fractionally lower for gas boiler no. 1 in the proposed method, this is more than offset by the lower “combi loss” of at least 207 kWh/yr. For example, the hot water load for a $30m^2$ property is 1112 kWh/yr (Table 1 SAP), so a combi loss of 207 kWh/yr less represents 19 %points improvement in summer efficiency. This will be mitigated to some extent because some of the heat losses in the winter reduce the central heating consumption. For a large property, say with floor area of $300m^2$, the new procedure would use a combi loss of 276kWh/yr less in 4589 kWh/yr, giving a 6 %point increase in efficiency.

For boiler no. 2, a similar argument applies to properties in excess of floor area of $80m^2$. For $30m^2$ properties the new method would mean both a 3% decrease in summer efficiency and a combi loss of 56kWh/yr more.

The break-even point is approximately $50m^2$ for boiler no. 2, below which the new method estimates a higher summer consumption. Above $50m^2$ the new method would result in lower summer consumption.

Table 9 Comparison of current and suggested parameters for four gas and oil boilers						
Boiler tested	Existing SAP 2005 parameters			Proposed new SAP parameters *(Differences shown in brackets)*		
	Combi Loss (kWh/yr) 30m² property	Combi Loss (kWh/yr) 80m² or higher property	SEDBUK efficiency	Combi Loss (kWh/yr) 30m² flat	Combi Loss (kWh/yr) 300m² house	Summer efficiency at the appliance (gross) under steady conditions
Instantaneous combi 1 (no keep-hot)	567	900	90.2%	360 *(-207)*	363 *(-537)*	90.0% (-0.2%)
Instantaneous combi 2 (keep-hot active)	567	900	91.1%	623 *(+56)*	624 *(-276)*	88.1% (-3%)
	Store heat loss [3] plus any combi loss in kWh/yr			Store heat loss plus any combi loss in kWh/yr		
Oil storage combi boiler 3	498 [4]		92.2%	3020[5] (+2522)		93.6%
Oil storage combi boiler 4	478		89.6%	3059 (+2581)		90.0%

For the two oil boilers the situation is different owing to the very low hot water efficiency (under 40% gross) and the new method would apply a large penalty of about 2500kWh/yr. In this case manufacturers would have nothing to gain by providing the test data, as current default assumptions for hot water performance are higher.

Section 6 also recommends introducing a lower summer season and higher heating season appliance efficiency, which in practice would mean a summer appliance efficiency of about 10 %points lower than SEDBUK (say about 80% gross). This 10 point decrease equates to an extra loss of between 115 and 390, still insignificant compared to the extra 2500kWh/yr. Setting a revised default storage loss of 3100 kWh/yr is the only way to deal with this, assuming boilers 3 and 4 are the worst cases. However, there is insufficient data to determine whether the high constant heat losses are due to the fuel (oil) or the fact that it is a storage boiler or a non-modulating boiler.

In conclusion it is proposed that only test data for gas boilers is allowed at present, and that further tests are carried out to determine a suitable default for oil boilers once a test procedure is established for them.

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[3] Based on insulation thickness of 25mm and volume of store of 48.5 litres or 71 litres using Table 2, 2a and 2b of SAP 2005 (i.e. 365 x Table 2 x Table 2a x Table 2b)
[4] Includes combi loss of 97.5 (see Table 3 of SAP: 600 – (vol – 15) x 15)
[5] Anyway of looking at the high constant losses, is that to achieve a loss of 500kWh/yr the summer appliance loss would have to 48% gross.

7.5 Appendix Q - Flue gas heat recovery systems

It is claimed that flue gas heat recovery systems reduce the amount of rejected hot water. This is taken into account in the algorithms in SAP Appendix Q and is the reason why the estimated savings for FGHRS attached to combi without a keep-hot facility are higher than those attached a combi boiler with a keep-hot facility.

If data from the EN13202 tests were to be used as described in part 6.2 or 6.3, the amount of waste energy in the rejected water would vary from the SAP 2005 assumptions and hence that assumed in Appendix Q.

Therefore if the proposal to accept hot water test data is accepted, the Appendix Q procedure will need revision by altering the savings credited to the reduction in rejected water. It is expected that this will not require a change in the coefficients but use an amendment based on the difference in savings between a boiler assuming no water is wasted and assuming the SAP 2005 level of waste (600 kWh/yr).

8 Control efficiency adjustments

SAP 2005 Table 4c makes an adjustment to the annual heating system efficiency for certain heating controls. These are

- Boiler interlock: Deduct 5 %points (gross) for failure to provide
- Weather and load modulation: Add 1 or 2 %points (gross) for LPG/oil and gas condensing boilers respectively
- Underfloor heating: Add 3 or 2 %points (gross) for LPG/oil and gas condensing boilers respectively.

With the introduction of a separate winter and summer efficiency, the above adjustments need deconstructing.

8.1 Boiler interlock

A boiler interlock is an arrangement of controls, rather than a physical device, that enables the boiler to be turned off when there is no call for space or water heating. In the absence of boiler interlock, the boiler fires even when there is no demand for space or water heating. A 5% reduction is applied to annual total for space and water heating efficiency to take this into account.

For regular boilers the 5 %point reduction should apply equally to space heating and water heating efficiency. Although this reduction will vary throughout the year the extra complication it introduces is not worth pursuing as the number of systems without boiler interlock is declining rapidly (this is because all replacement systems must be fully pumped and have boiler interlock).

For combi boilers, the 5 %point reduction can only apply to space heating efficiency as the hot water interlock is intrinsic.

Lack of thermostatic control (by electrical switching) of room temperature is treated as no boiler interlock. The proposals for boiler interlock are therefore as noted in 8.5.

8.2 Condensing boiler with weather compensator

Weather compensators adjust the temperature of the water circulating through the heating system according to the temperature outside the building. They may do this by operating a mixing valve, or limiting the flow or return temperature to the boiler. If the effect of a weather compensator is to lower the temperature of the water in the boiler while it is firing then the boiler efficiency is raised because of the higher temperature differential between the combustion gases and water. Weather compensators that have mixing values will not result in cooler water entering the boiler and hence no improvement in efficiency can be credited.

The efficiency improvements assigned in SAP 2005 due to controls were derived from a theoretical consideration (ref 9) assuming:

- a change in efficiency of 0.178% per K and 0.28% per K decrease in return temperature for oil and gas boilers respectively,
- space heating consumption was 73% of the total heating and water heating annual consumption
- the weather compensator reduces the average temperature by 7.2K.
- 0.3 %point reduction due a reduction to case losses.

Using updated gas boiler efficiency curves[6] shows the efficiency varies by 4.1% between 30°C and 40°C at 30% part-load, or 0.41% per K (see figure 1). This equates to 3% over 7.2K, which will only apply to space heating efficiency.

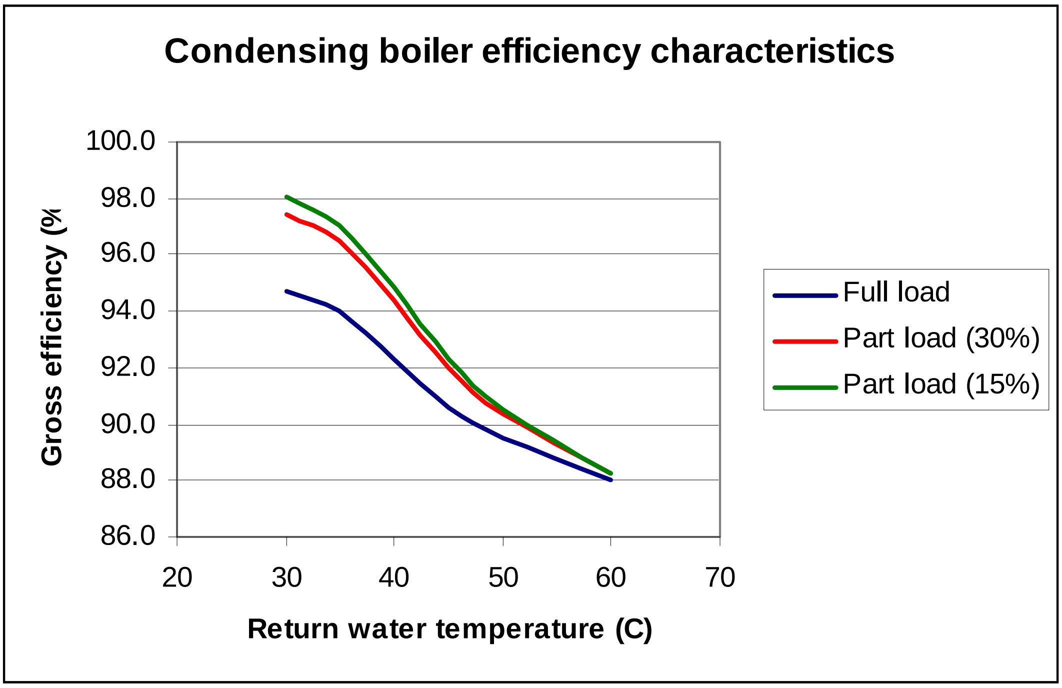

Figure 1: Typical gas boiler temperature-efficiency (gross) characteristics

Using updated oil boiler efficiency curves[7], the efficiency varies by 2% between 30°C and 40°C or 0.41% per K (see figure 2). This equates to 1.44% over 7.2K, which will only apply to space heating efficiency.

It is therefore proposed to amend the efficiency adjustments due to a weather compensator to +3 and +1.5 %points of the space heating efficiency for gas and LPG/oil boilers respectively. No efficiency improvement is credited to the water heating.

[6] These were supplied by HHIC as typifying the characteristics of a modern gas condensing boiler and used in the MTP controls project in 2007.
[7] These were supplied by OFTEC for the same project.

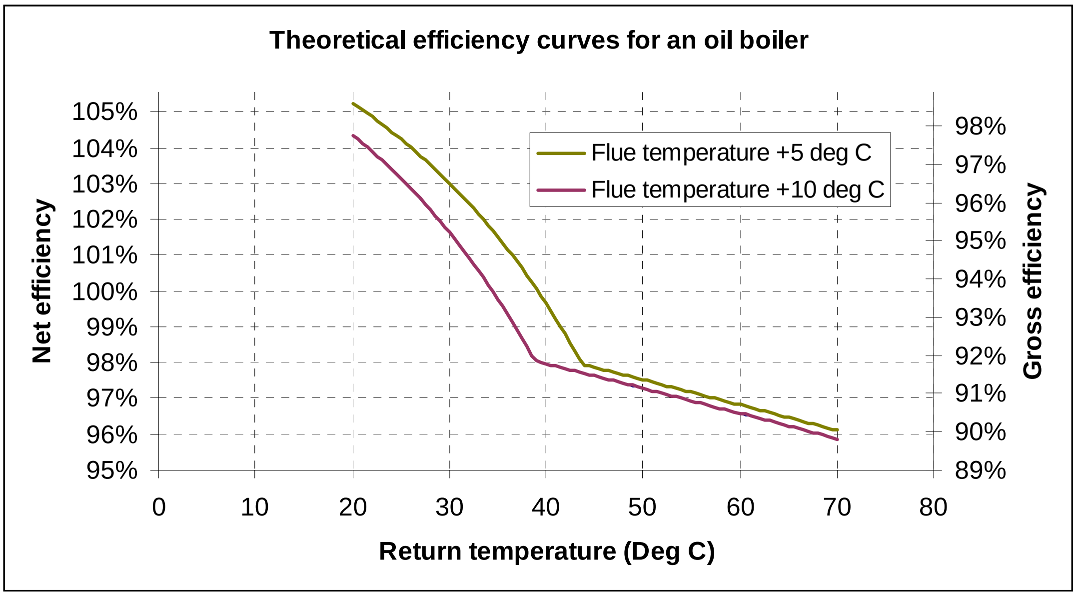

Figure 2: Typical oil boiler temperature-efficiency (net) characteristics

8.3 Condensing boiler with load compensator

Load compensators adjust the temperature of the water circulating through the heating system according to the temperature inside the building. They may do this by operating a mixing valve, or limiting the flow or return temperature to the boiler. If the effect of a load compensator is to lower the temperature of the water in the boiler while it is firing then the boiler efficiency is raised because of the higher temperature differential between the combustion gases and water. To achieve and maintain an efficiency benefit the internal temperature sensor must be able to distinguish between mild days and cold days, and alter the water temperature accordingly. To do so consistently and maintain a limit on circulation temperature over long periods, the internal sensor would need to learn the temperature characteristics of the building under standardised conditions over a full year. As this requirement does not form part of the currently agreed definition of a load compensator, it is recommended that there should be no efficiency benefit assigned in SAP.

8.4 Condensing boiler with under-floor heating

Boilers coupled to under-floor heating emitters can operate at low temperatures provided the system is designed to work at lower temperatures. The cooler water must enter the boiler for there to be an efficiency gain. The efficiency improvement of 3 %points and 2 %points for gas and oil respectively is currently stated in SAP 2005 Table 4c. This applies only to space heating, as it is restricted to boilers dedicated to underfloor heating and cannot be claimed for boilers that also provide hot water service (see SAP Table 4c footnote b).

8.5 Controls proposal

The proposed amendments to the efficiency adjustments in Table 4c of SAP are:

- Weather compensator: +3 and +1.5 %points (gross) of the space heating efficiency for gas and LPG/oil respectively. No efficiency improvement is credited to the water heating efficiency (see 8.2).
- Load compensator: 0% (see 8.3).
- No boiler interlock with regular system: -5 %points is applied to both the space and water heating efficiency (see 8.1).
- No boiler interlock with combi system: -5 %points is applied to the space heating efficiency only (see 8.1). No penalty is applied to the water heating efficiency.
- Underfloor heating adjustment: remains as at present and applies to the space heating efficiency only (see 8.4). No efficiency improvement is credited when the boiler provides both services (see SAP Table 4c footnote b).
- Condensing boilers with thermal store: remains as at present.

9 Biofuels

The characteristics of liquid biofuels, as an alternative to mineral oil, can be recognised for oil boilers when specific blends have been defined, their provenance can be assured, and the price and carbon emission factor (in kg CO_2 / kWh) established. The Boiler Efficiency Database will be adapted to accept entries for boilers tested with these fuels. If tested with mineral oil instead, evidence will be required to show that the boiler efficiency is not lower when burning biofuel.

Recognition of individual boiler installations using biofuels will also depend on a suitable scheme for fuel and boiler labelling, and whether reversion to mineral oil or other blends is feasible.

10 Community heating

10.1 Efficiency of gas and oil boilers

The SAP efficiency procedure for a boiler serving a single dwelling is documented in SAP 2005 (Appendix D). 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 SAP 2005. This may lead to ambiguity, confusion, and unfair interpretation.

A report (ref 9) describes the current status and recommends an approach for community boilers. It recognises that the approach in the "Non-domestic heating, cooling and ventilation compliance guide" (NDHCVCG) is not valid for use in SAP. It recommends that the SEDBUK procedure is extended to community systems without alterations to coefficients because any differences in the coefficients are likely to be small. An additional step is required because of multiple boiler systems.

For multiple boilers the following additional step is proposed:

First calculate the SEDBUK (or winter and summer efficiencies) for each boiler and note each maximum heat output.

The overall SEDBUK (or winter and summer efficiency) is calculated as the power-weighted average of the SEDBUK (or winter and summer) efficiencies thus:

$$\eta_{s,se} = \frac{\sum_{i=1}^{i=n} (R_i \times \eta_{i,se})}{\sum_{i=1}^{i=n} (R_i)} \qquad \text{........} \quad 10$$

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

$\eta_{i,se}$ is the gross SEDBUK, summer or winter efficiency boiler 1, 2, 3, etc to n

$\eta_{s,se}$ is the gross SEDBUK, summer or winter efficiency of bank of boilers.

10.2 Distribution losses

Distribution loss factors are given in SAP Table 12c. The values in SAP 2005 may underestimate losses in schemes where the linear heat density[8] is low; ie, in schemes where the heat delivered is small in comparison with the length of pipes in the heat distribution network. This may occur in widely spaced housing developments with relatively low heat load. It is proposed that in SAP 2009 the values in Table 12c should apply only in community heating schemes where the linear heat density is 2MWh/year/m or higher.

[8] Linear heat density is the heat delivered to premises by the community heating distribution network in MWh/year divided by the total length of the distribution network (the total "trench length") in metres.

Where the linear heat density is lower, or is not known, then a distribution loss factor for the scheme should be calculated using one of two methods.

Method 1: If the scheme has full heat metering at all connections to the distribution network then the distribution loss factor is given by the total heat input to the network from the energy centre(s) divided by the sum of the heat outputs at all connections, both measured over a period of one year (the same period for both). Connections on the consumer side of the network may be metered either at building or apartment level, so long as all heat is counted.

Method 2: The distribution loss factor is calculated from the heat lost by the pipes in the distribution network, using the formula

$$1 + \text{linear loss} \times \text{total length of pipework} \div (\text{total heat supplied} \times 114)$$

where:

'linear loss' is the average heat loss per metre run of pipework in W/m, calculated in accordance with ISO 12241, equations (8) and (9);

'total length of pipework' is the length of the distribution network pipes for the whole scheme in metres;

'total heat supplied' is the heat supplied from the energy centre(s) to the distribution network over a whole year, in MWh/yr;

114 converts MWh/year to W.

If the result is lower than the value in SAP Table 12c then the value from Table 12c should be used instead.

It would be for the community scheme manager (or designer in the case of a new scheme) to calculate the distribution loss factor. If the distribution loss factor cannot be determined from scheme data a default value of 1.5 would apply.

As a longer term solution it is proposed to collect relevant technical data for each community heating scheme, including annual heat and fuel quantities, to enable performance to be calculated more specifically. This would be made available for SAP assessments from a database.

11 Influence of the EuP Directive

Implementation measures under the Eco-design of Energy Using Products Directive (EuP) are expected to change the way in which the energy performance of boilers and water heaters (including the water heating function of combi boilers) is tested and declared. It is anticipated that additional boiler efficiency tests, using the same test methods as at present, will be required and that water heating performance will be measured in accordance with the European standard EN 13203 (ref 2). The EuP is intended to replace the Boiler Efficiency Directive (BED) with regard to the minimum allowable boiler efficiencies.

The EuP may provide access to better and more boiler efficiency data for use in SEDBUK and SAP as the proposal includes restricting tests to steady state. That will improve accuracy and repeatability and rationalise test temperatures across different fuels.

The BED specifies two efficiency tests:

- high temperature and full-load
- low temperature and part-load.

The EuP proposals currently specify efficiency tests at:

- low temperature and full-load
- high temperature and full-load
- low temperature and 30% part-load or minimum load if higher
- high temperature and 30% or minimum load if higher.

However, any recommendation concerning EuP and SAP must await finalisation of the implementation of the EuP for boilers. It is unlikely that implementation measures will be agreed and announced in time for SAP 2009 to take them into account.

The EuP is not expected to provide seasonal efficiency figures that could be taken into SAP directly. Whatever new test results are obtained for the purposes of the EuP, further calculations will be necessary to allow for:

- conversion from net to gross calorific values;
- separate treatment of energy and CO_2 figures for fuel and power;
- combined duty (space heating and water heating together during the heating season)
- intermittent heating in accordance with the SAP demand pattern;
- controls, climate, and occupancy factors representative of heating systems in the UK.

In particular, recognition of the different carbon factors for heating fuels (natural gas, LPG, oil) is an essential element of the SAP calculation for compliance with the carbon emission target. This cannot be dealt with in a single power conversion factor (relating electricity to all other fuels) as proposed in the current version of the EuP system models for boilers and water heaters.

12 Conclusions

The introduction of the energy balance validation method has enabled a better estimate of the theoretical maximum efficiency of condensing boilers by fuel to be established. Minor alterations to the test efficiency maxima and coefficient for oil boilers have been developed in sections 2 and 3. These remove some former anomalies in the SEDBUK equations.

A statistical analysis of over 100 independently tested boilers from ten separate trials carried out from 2003-7 revealed that BED test efficiencies quoted by manufacturers are consistently higher (ref 3), and that upward bias increases with claimed efficiency. To give a more realistic indication of boiler efficiency in SAP there should be a deduction that increases with efficiency, as explained in section 5.

With the introduction of more stringent regulations for building fabric standards, the water heating component becomes a much higher proportion of the total heating and hot water load than it was 10 years ago when SEDBUK was introduced. The annual SEDBUK figure should therefore be deconstructed into its seasonal components. From separate summer and winter season efficiencies SAP can derive the monthly space heating efficiency and water heating efficiency. The methodology is described in section 6. Existing entries in the boiler database where full- and part-load efficiencies have been submitted can also be treated using the equations in section 6.

Separating the annual efficiency into its space and water heating components means a revision to heating control efficiency adjustments is necessary. The revised adjustments make use of recent data for boiler efficiency-temperature relationships (see section 8).

The main weakness of SEDBUK is that it is unable to include hot water test data, as at present there is no legal obligation on manufacturers to measure and declare hot water performance. Now that a European standard method for doing so has been ratified, and the EuP Directive is to be implemented, test data will become more widely available. A way of allowing hot water test results to be used in SAP has been devised (see section 7). If hot water test data is allowed, a minor revision to the Appendix Q procedure for flue gas heated recovery systems will also required (see 7.5).

Community heating boiler(s) that serve more than one dwelling have never been included in the SEDBUK method. Recent analysis of the different factors involved with community boilers concludes that the SEDBUK coefficients will be reasonably accurate for community heating, and hence the newly proposed winter and summer coefficients will be also be suitable. For banks of boilers, an additional step is necessary to determine the combined efficiency of differently sized boilers (see section 10).

13 References

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Appendix A: Making use of EN 13203-2 data in SAP

This Appendix shows the derivation of the procedure to make use of hot water test data in SAP.

As noted in section 6, the simple replacement of the efficiency of heat to primary water (required by SAP) by the DHW efficiency (produced by EN 13203-2) is not sufficient and would be incorrect. The amount of energy associated with hot water storage and rejected hot water must be separated out from the DHW efficiency so that SAP can calculate any advantageous heat gains that may partly offset the space heating consumption (i.e. the heat replacement effect).

A more complicated approach is required to extract from the DHW efficiency the energy lost in any rejected water and any constant loss (independent of water volume) associated with a keep-hot facility or hot water storage.

The procedure for calculating these quantities is developed below.

The fuel used for the production of a given volume of hot water as calculated in SAP is:

$$F = \frac{Q_{dhw} + Q_{dhw} r_j + Q_{fix}}{\eta_0} \qquad \text{A1}$$

F is the fuel required

Q_{dhw} is the energy of hot water required

r_j is the fraction of heat rejected.

The values required by SAP are

Q_{fix} the amount independent of the volume usage, the combi loss or storage loss

$Q_{dhw} \times r_j$ - the amount of reject water

η_0 is the appliance “fuel to water” heat transfer efficiency

If EN13202 data is available these can be obtained as follows in A2 and A3.

A2 When only one test schedule result is available

First consider the case where only the no. 2 schedule result from EN 13202-2 is quoted.

Applying the EN 13203-2 results to equation A1 gives:

$$F_{EN2} = \frac{Q_{dhw,EN2}(1+r_j)+Q_{fix}}{\eta_0} \quad \text{......} \quad A2$$

where

F_{EN2} is the gross energy in the fuel supplied during EN 13203-2 schedule no. 2 test

$Q_{dhw,EN2}$ is the energy of useful hot water supplied during EN 13203-2 schedule no. 2 test

The rest are defined in part A1.

Rearranging A2 to solve for Q_{fix} gives

$$Q_{fix} = \eta_0 F_{EN2} - Q_{dhw,EN2}(1+r_j) \quad \text{......} \quad A3$$

The definition of DHW efficiency during an EN 13203-2 test is:

$$\eta_{EN2} = Q_{dhw,EN2} \div F_{EN2} \quad \text{......} \quad A4$$

Replacing F_{EN2} in A3 by using A4 gives

$$Q_{fix} = Q_{dhw,EN2}\left((\eta_0 \div \eta_{EN2}) - 1 - r_j\right) \quad \text{......} \quad A5$$

Provided η_0 and r_j are known Q_{fix} can be estimated. The other values are known from the test results.

The rejected energy can be approximated to:

$$r_j = 0.5 \times \frac{V_{j,EN}}{V_{EN}} \quad \text{......} \quad A6$$

where

$V_{j,EN}$ is the reject water volume during the test

V_{EN} is the useful volume hot water during the test

The η_0 can be approximated to the full-load efficiency (gross) after capping.

A3 When results from two test schedules are available

Applying A1 to each test schedule gives

$$F_{EN2} = \frac{Q_{dhw,EN2}(1+r_{j,EN2}) + Q_{fix}}{\eta_0} \quad \text{............ A8}$$

$$F_{ENx} = \frac{Q_{dhw,ENx}(1+r_{j,ENx}) + Q_{fix}}{\eta_0} \quad \text{............ A9}$$

Substituting the domestic hot water efficiency into A8 and A9 gives

$$\frac{Q_{dhw,EN2}}{\eta_{EN2}} = \frac{Q_{dhw,EN2}(1+r_{j,EN2}) + Q_{fix}}{\eta_0} \quad \text{............ A10}$$

$$\frac{Q_{dhw,ENx}}{\eta_{ENx}} = \frac{Q_{dhw,ENx}(1+r_{j,ENx}) + Q_{fix}}{\eta_0} \quad \text{............ A11}$$

A10 and A11 are two simultaneous equations and can be solved as follows for Q_{fix} and η_0

First solving for Q_{fix}

$$\eta_0 = \frac{\eta_{EN2} Q_{dhw,EN2}(1+r_{j,EN2}) + \eta_{EN2} Q_{fix}}{Q_{dhw,EN2}}$$

$$= \frac{\eta_{ENx} Q_{dhw,ENx}(1+r_{j,ENx}) + \eta_{ENx} Q_{fix}}{Q_{dhw,ENx}} \quad \text{............ A12}$$

Rearranging gives:

$$Q_{fix} = \frac{\eta_{EN2}(1+r_{j,EN2}) - \eta_{ENx}(1+r_{j,ENx})}{\dfrac{\eta_{EN2}}{Q_{ENx}} - \dfrac{\eta_{ENx}}{Q_{EN2}}} \quad \text{.......... A13}$$

Solving for η_0 gives

$$Q_{fix} = \frac{\eta_0 Q_{dhw,EN2}}{\eta_{EN2}} - Q_{dhw,EN2}(1+r_{j,EN2})$$

$$= \frac{\eta_0 Q_{dhw,ENx}}{\eta_{ENx}} - Q_{dhw,ENx}(1+r_{j,ENx}) \quad \text{.......... A14}$$

$$\eta_0 \frac{Q_{dhw,EN2}}{\eta_{EN2}} - \frac{Q_{dhw,ENx}}{\eta_{ENx}}$$

$$= -Q_{dhw,ENx}(1+r_{j,ENx}) + Q_{dhw,EN2}(1+r_{j,EN2}) \quad \text{.......... A15}$$

$$\eta_0 = \frac{(Q_{dhw,ENx}(1+r_{j,ENx}) - Q_{dhw,EN2}(1+r_{j,EN2}))}{(\dfrac{Q_{dhw,ENx}}{\eta_{ENx}} - \dfrac{Q_{dhw,EN2}}{\eta_{EN2}})} \quad \text{.......... A16}$$

So

$$F = \frac{Q_{dhw} + Q_{dhw} r_j + Q_{fix}}{\eta_0}$$

With η_0 from A16 and Q_{fix} from A13 leaving only r_j to solve.

r_j can be determined by linear interpolation/extrapolation between $r_{j,ENx}$ and $r_{j,EN2}$