Technical Papers supporting SAP 2009

Revision to the SEDBUK procedure for oil boilers

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Contents

1 Introduction

The equations for oil boilers to calculate the seasonal efficiency (SEDBUK) are:

Regular $E_{ann} = (PLE + FLE) \div 2 - 0.0$ 201

Combi $E_{ann} = (PLE + FLE) \div 2 - 2.8$ 202

Storage Combi $E_{ann} = (PLE + FLE) \div 2 - 2.8 + (0.209 \times b \times L \times V_{cs})$ 203

(see Appendix D, ref[2])

There were two unresolved problems during the development of the seasonal method concerning oil boilers.

- For non condensing boilers the average difference between the full and part-load efficiency was negative; that is the part load efficiency was higher than the full load. It was not clear whether this was due to experimental uncertainty or some heat mechanism not represented adequately in the SEDBUK method. A pragmatic approach was adopted that set the coefficient for regular boilers to zero.

- There was no data available to derive the coefficient for oil combi boilers (eg -2.8) so for these it was set to same as that for on-off gas combi boilers.

This paper re-examines the problems in the light of new data from April 2007 issue of the Boiler Efficiency Database.

This paper is only concerned with *on-off non-condensing* boilers, although the equations apply to both condensing and non condensing.

2 Boiler Efficiency Database figures

The distributions of the average difference between the full and part load efficiency for 686 non-condensing on-off oil boilers and 485 gas on-off boilers are illustrated in the histograms in Figures 1 and figure 2, together with sample mean and standard deviation. The curve represents normal distribution based on the sample mean and standard deviation.

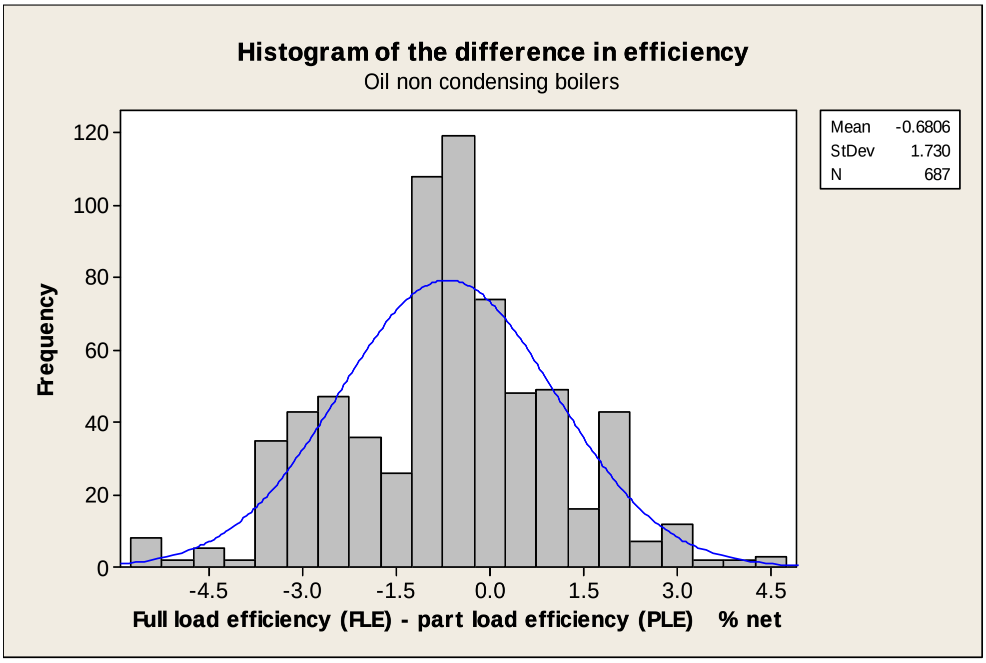
As the distributions in Figures 1 and 2 have failed a statistical test to show they are not normal, it can be concluded that they are normal (approximately), and hence confidence intervals for the population mean can be reliably established.

There is a 95% chance that the mean difference for gas boilers lies between +0.56% and +0.79% and so is highly likely to be positive as expected.

There is a 95% chance that the mean difference for oil boilers lies between -0.80% and -0.55% and so is highly likely to be negative; not expected.

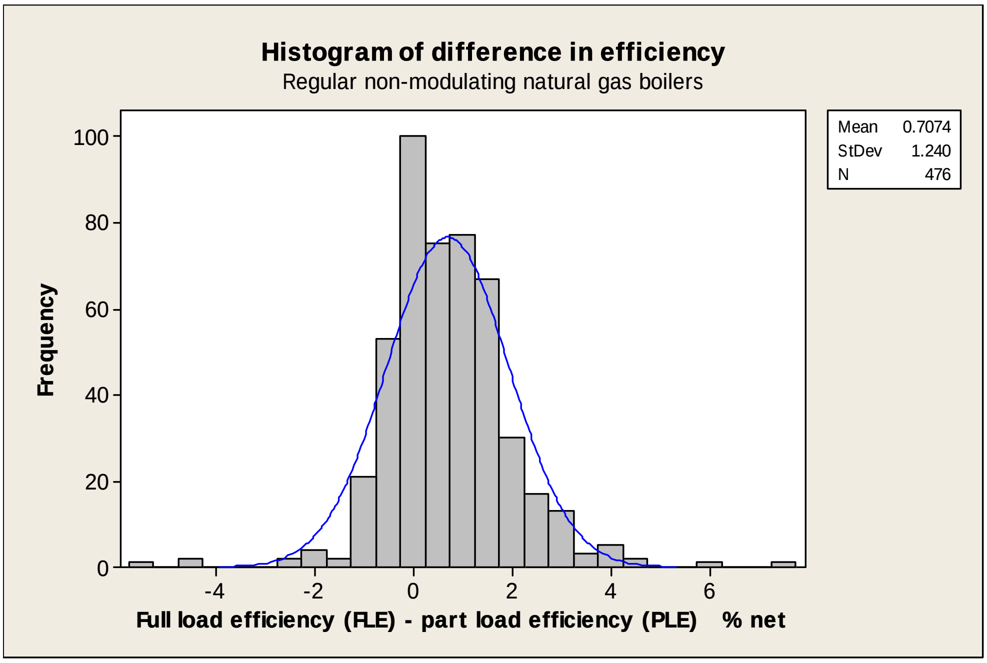
The statistically significant higher standard deviation (at 95% confidence) for oil indicates that there is evidence to support the proposition that the differences for oil vary more than for gas.

Figure 1



-0.6806 net points = - 0.6377 gross points

Figure 2



+0.7074 net points = + 0.6374 gross points

Part 3 explores possible mechanisms that would explain why the efficiency at full load differs from that at part load.

3 Thermal mechanisms

The following conditions differ between the full and part load tests for non-condensing non-modulating boilers (Ref[3[):

- Boiler water temperatures - full load 80°C/60°C and part load 53°C/47°C
- Firing time - full load continuous and part load 3 minutes on and 7 minutes off.

Six thermal mechanisms that influence the difference between the full and part load efficiency are identified as follows.

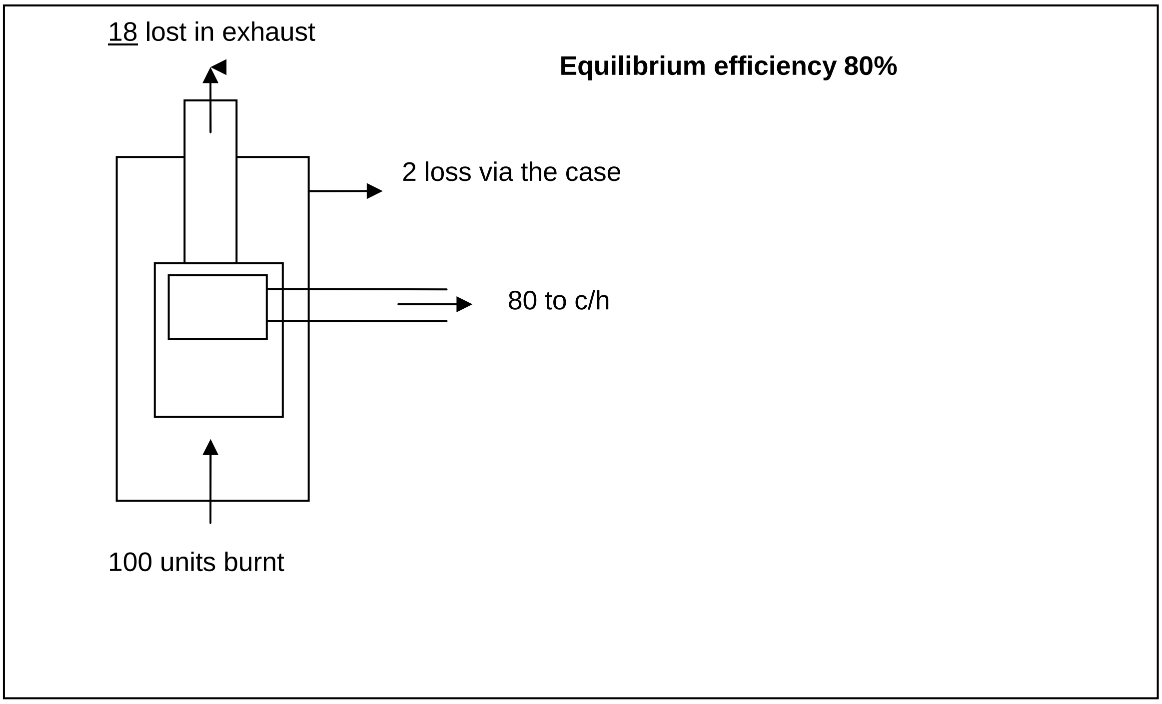
1. Case temperature - Casing heat loss will vary between full and part load tests. During the full load test the case heat loss rate will be higher because the boiler is warmer than at part load.. This effect will contribute a *negative* amount to the full load minus part load efficiency.
2. Case loss and intermittent firing - When expressed as a percentage of the heat input, the case heat loss will be higher at part load because it is a cyclic test and the full load test is continuous. This effect will contribute a *positive* amount to the difference.
3. Purge loss - Before a boiler fires it is purged with fresh air to ensure safe ignition. The heat loss during the purge will reduce the efficiency during cyclic operation of the part load test. Thus it will contribute *positive* amount to the difference between the full and part load efficiency.
4. Temperature difference across the heat exchanger – The rate of heat exchange will depend, amongst other factors, on the temperature difference between the combusted gases (i.e flame temperature) and water temperature in the boiler. The gas-to-water temperature difference is lower during the full load test than the part load test and so may lead to lower efficiency at full load. This effect will contribute a *negative* amount to the difference between full and part load efficiency.

The fifth and sixth mechanisms require an introductory explanation.

First consider what happens during the full load test. Immediately after purging, most, but not all, of the heat in the burnt gas is extracted. The small amount of heat that is not extracted will either escape in the exhaust or through the body of the boiler and warm the inner part of the boiler (e.g. the combustion chamber and heat exchanger).

As the boiler continues firing for a prolonged period, the inner part of the boiler will reach thermal equilibrium and the boiler will reach its steady-state efficiency, as in the full load test. An example of a boiler in thermal equilibrium with a full load efficiency of 80% (gross) is given in Figure 3. Note for this example that 18 units are lost in the exhaust.

Figure 3



Full Load Efficiency (FLE) = 80 /100 = 80%

Now consider the part load cyclic test. During the firing time, the inner part of the boiler will warm. During the "off" part of the cycle the central heating pump is still circulating water through the boiler and so some of the heat stored in the inner part of boiler during the firing time can be transferred into the central heating water.

This can potentially add to or detract from the difference between the full and part load efficiency, as explained next.

5. Detrimental transient effect. If the inner part of the boiler was warmed by heat that would have otherwise been extracted directly to the central heating water, it will reduce the part load efficiency.

   For example, consider the case illustrated in Figure 4 (on-time) and Figure 5 (off-time). During the "on" time of 3 minutes, if the boiler has a gross full load efficiency of 80% (Figure 3) then the heat loss rate out the flue is 3 x 18 units. If 4 units are stored over 3 minutes in the inner part of the boiler, then this leaves only 76 units over three minutes that can usefully be extracted. The losses via the case do not concern us here but are the same as the full load case of 2 units spread evenly over the 10 minutes of test.

   Figure 5 shows what happens to 3 x 4 units stored during the "off" part of the cycle. Say for example ¾ is extracted and ¼ is lost. Then the part load efficiency is 79% (see calculation example below Figure 5) which is 1% lower than the full load efficiency.

Figure 4

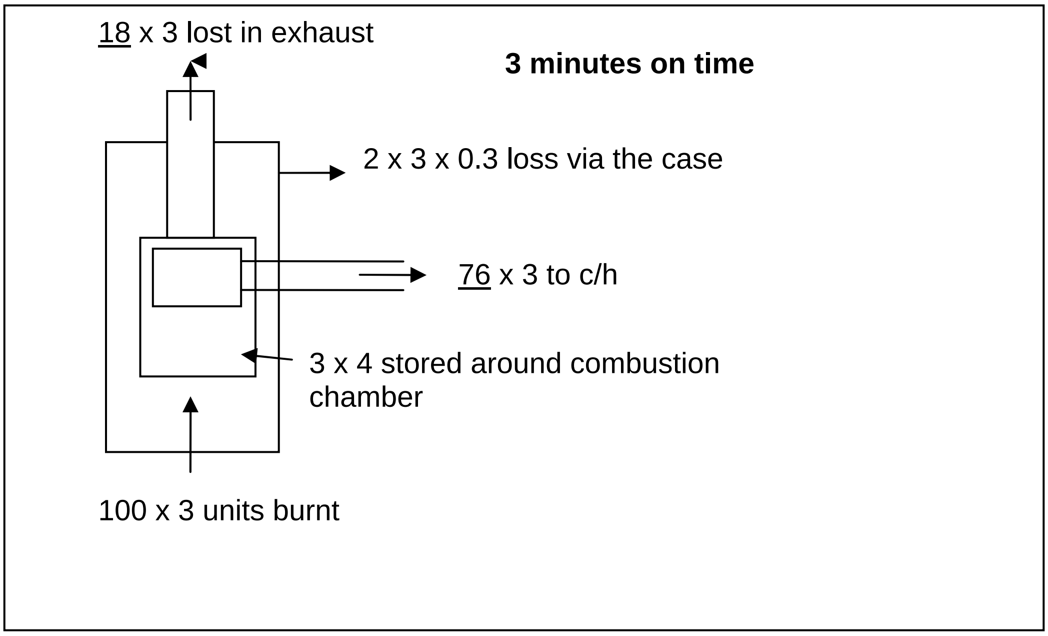
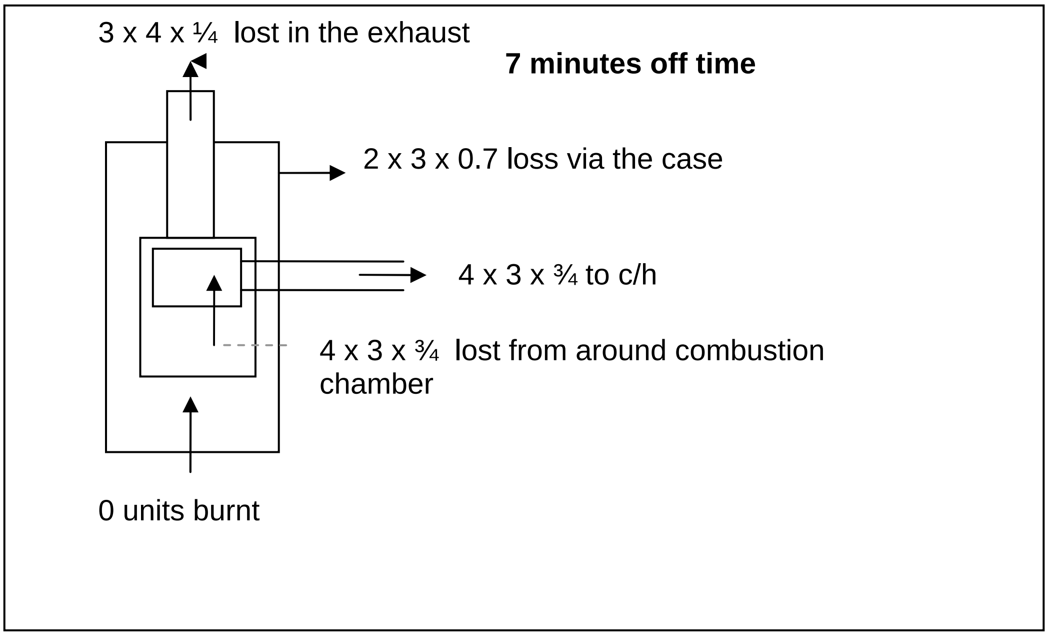


Figure 5



Part load efficiency (PLE) = [(3 x 76) + (3 x 4 x ¾)] ÷(3 x 100) = 79%
So FLE – PLE = 80% - 79% = +1 %point

6. <u>Beneficial transient effect</u> – Here the inner part of the boiler is warmed by heat before it has chance to escape making a negative contribution to the difference more negative, as the example illustrated in figure 6 and 7. Here instead of 18 units lost out the flue (figure 6), there are only 14 units lost with the remaining 4 units stored during on-part of the cycle. During the off-part of the cycle ¾ of the stored is usefully extracted giving a part load efficiency of 83% (i.e. 3% points higher than the full load).

Figure 6

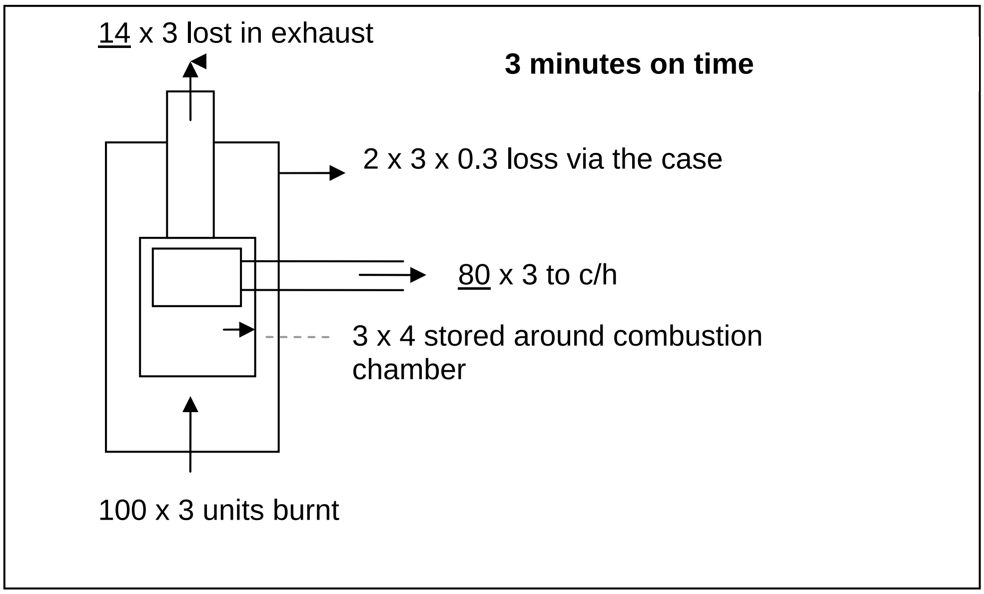
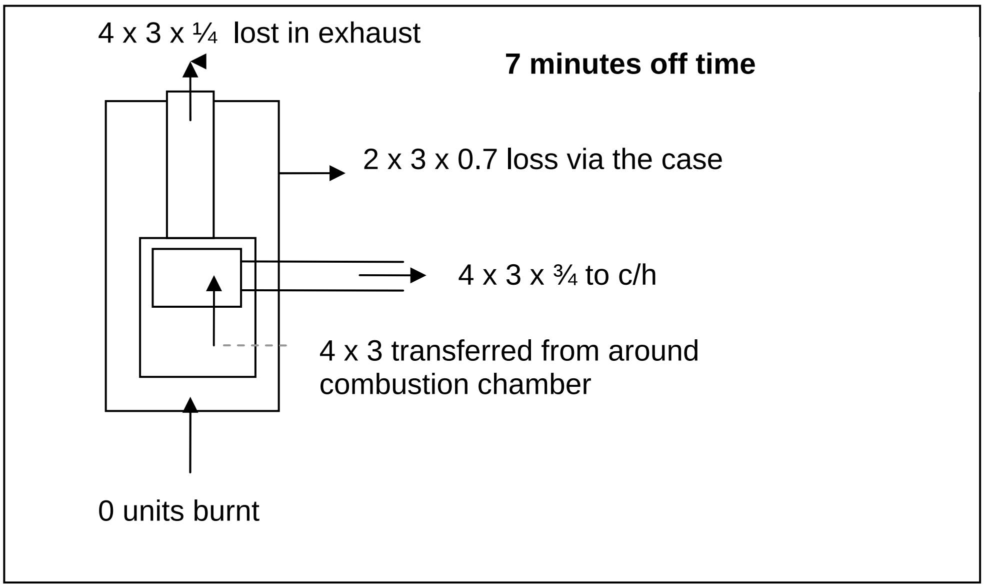


Figure 7



Part load efficiency (PLE) = [(3 x 80) + (3 x 4 x ¾)] ÷ (3 x 100) = 83%

FLE – PLE = 80% - 83% = -3 %points

Of course, in practice the numbers will differ from the example illustration and for each boiler. The numbers were selected only to illustrate the detrimental and beneficial storage effects.

3.1 Relevance of mechanisms

The differences in test temperatures, (mechanism 1), and firing times (mechanism 2) on the case heat loss and hence on efficiencies are already accounted for in SEDBUK coefficients. Mechanism 2 has a larger impact than mechanism 1, so the expected difference between the full and part load efficiency is positive.

Mechanism 3 the purge loss is not included in SEDBUK coefficient, but it is explicitly in the measured part load efficiency. It does not explain why the difference between the efficiency at full and part is negative. In fact, the opposite is true. It contributes a positive amount to the difference between efficiencies.

Mechanism 4 the variation of heat transfer with temperature across the across the heat exchanger is not included in the SEDBUK coefficient as it was reckoned that this is small for non condensing boilers. For condensing boilers mechanism 4 is large and is included by virtue of the part load test is undertaken at lower temperatures than for non-condensing boilers, but here condensing boilers.are not an issue. The result of mechanism 4 for non condensing boilers is likely to be the similar for natural gas and oil boilers. And so it is unlikely to explain why gas boilers have a positive difference between the full and part load efficiency and why oil boilers have a negative difference.

Mechanism 5 the detrimental transient effect is not included in the SEDBUK coefficient but it adds a positive contribution to the difference between the efficiency at full load and part load. And so does not explain why oil boilers have, on average, a negative difference.

This leaves mechanism 6 the *beneficial transient effect* is also not included in the SEDBUK coefficient and has the potential to explain why the results in the difference between the full and part load efficiency for oil boilers and gas boilers are of opposite signs. Oil boilers are usually bulkier (i.e greater metal and water content) and better insulated than gas boilers. This means that oil boilers have the potential to store more heat inside of the boiler and utilise the beneficial transient effect.

4 Size of the *beneficial transient effect*

It is hypothesised that the *beneficial transient effect* is too small to notice in gas boilers but not in oil boilers. If true the size of the average *beneficial transient effect* can be determined by:

Oil *beneficial transient effect* $= (\text{FLE} - \text{PLE})_{\text{oil}} - (\text{FLE} - \text{PLE})_{\text{gas}}$

So using the average differences for 686 non condensing on/off oil boilers and 485 gas boilers in the boiler database (April 2007) quoted below figure 1 and 2 means that:

Oil *beneficial transient effect* = - 0.6377 – (0.6374) = - 1.2751% gross points

5 Consequence for the oil coefficients

The coefficients in the equations (SAP 2005, ref[2])) represent the effect on the efficiency of the case heat loss as described by mechanism 1 and 2 in domestic installations.

For on/off regular appliances they were derived from:

Coefficient (case loss effect) = - 2.14 x (FLE – PLE) (1)

(2.14 is derived from the boiler firing times monitored in UK homes (ref [1]). For gas, regular on/off boilers, (FLE – PLE) was 1.16% gross points giving the coefficient of 2.5 for equation 101 in SAP, Appendix D, Ref [2]).

For oil boilers (FLE – PLE) was negative and taken as zero giving a zero coefficient (SAP 2001).

5.1 Regular oil coefficient

5.1.1 Case loss component

The zero coefficients can be revised as indicated next.

The difference in between the full and part load can be considered as the sum of a component representing the case heat loss and the *beneficial transient effect* . Or put mathematically.

$(\text{FLE} - \text{PLE})_{\text{(total)}} = (\text{FLE} - \text{PLE})_{\text{(case loss part)}} + (\text{FLE} - \text{PLE})_{\text{(beneficial transient effect)}}$

Rearranging to solve for $(\text{FLE} - \text{PLE})_{\text{(case loss part)}}$ gives:

$(\text{FLE} - \text{PLE})_{\text{(case loss part)}} = (\text{FLE} - \text{PLE})_{\text{(total)}} - (\text{FLE} - \text{PLE})_{\text{(transient effect)}}$

Using the actual difference for the oil boilers and effect of beneficial effect estimated in part 4 then:

$(\text{FLE} - \text{PLE})_{\text{(case loss part)}} = -0.6377\% + 1.2751\% = + 0.6374$

Applying this to the coefficient equation (1) to give the component of coefficient due to case heat loss is:

$\text{Coefficient}_{\text{(case loss component)}} = - 2.14 \times 0.6374 = - 1.364$ % gross points

5.1.2 Oil *beneficial transient effect* annual component

When installed in a home, the *beneficial transient effect* is only beneficial when the boiler is cycling on the boiler thermostat. During room thermostat firing cycles or a cylinder thermostat firing cycle, water is not circulating during the “off” part of the cycle and so heat previously stored during the “on” part of the cycle cannot be extracted.

For on-off boilers during the heating season, gas consumed during boiler thermostat cycles amounted to 60.5% of the total, during room thermostat and/or cylinder thermostat cycles it amounted to 31.9% and during the last cycle of a heating period it amounted to 7.6% (see u. v and w weighting factors - Appendix C, BG Technology R2485)

The precise data on cylinder thermostat cycles and boiler thermostat cycles during the summer season was not measured. The summer heating requirement was taken as 9% of the annual heat requirement (ref [1]).

So annually, between 60.5% and 69.5% of the fuel consumed occurs during boiler thermostat cycles and can potentially benefit from the *beneficial transient effect*. Most of fuel consumed in the summer is likely to be consumed during boiler thermostat cycle (i.e when there are two or more firing intervals each time the cylinder is heated). Therefore, taking the upper bound as the annual amount seems reasonable estimate.

Assuming 69.5% of the annual fuel is consumed during boiler thermostat cycles then, 69.5% of oil storage effect is potentially beneficial. The annual formulae (i.e. 0.5 x PLE + 0.5 x FLE + ……) already contains 50% of the oil beneficial transient in the part load measurement. Therefore, component of the oil coefficient for regular boilers due to *beneficial transient effect* is

69.5% – 50% = 19.5 %points.

The component of oil coefficient for regular boilers is therefore:

$\text{Coefficient}_{\text{(beneficial transient effect)}} = 1.2751 \times [\ (0.695 - 0.5\ ] = +\ 0.2486$

5.1.3 Total coefficient

The total coefficient for oil regular boilers is simply the sum components in parts 5.1.1 and 5.1.2:

$$\text{Coefficient} = \text{Coefficient}_{\text{(due to case loss)}} + \text{Coefficient}_{\text{(beneficial transient effect)}}$$

$$\text{Coefficient} = -\ 1.364 + 0.2486 = -1.1$$

5.2 Coefficient for oil combi boilers

The 2.8 coefficient (SAP 2001) for on-off combi boilers appliances was derived from:

$$\text{Coefficient}_{\text{(case loss effect}}) = -\ 4.5 \times (\text{FLE} - \text{PLE}) \qquad (2)$$

and was based on the amount of gas used during boiler thermostat operation of 45.4% with 9% for the summer ((see u. v and w weighting factors, Appendix C, ref[1]).

Following the same approach as in section 5, but using equation (2) rather than (1) and noting for combi boilers that the beneficial transient effect (1.2751) and case loss effect (0.6374) are the same as for regular boilers estimated in part 5.1.2 and 5.2.1 respectively the:

$$\text{Coefficient} = \text{Coefficient}_{\text{(due to case loss)}} + \text{Coefficient}_{\text{(due to beneficial transient effect)}}$$

Coefficient = 4.5 x 0.6374 + (0.454+0.09-0.5) x (1.2751)
= -2.8

Therefore no change to the coefficient for combi oil boilers is necessary.

6 Maximum permitted efficiency

The maximum permitted part load efficiency for non condensing boilers load was set at 1% below the permitted maximum at full load. Assuming the beneficial transient effect is real for oil boilers, then the maximum permitted values for oil boilers at part load needs lifting. The estimated average oil beneficial transient effect is 1.34 net oil points. How much higher this could be is impossible to say, but a pragmatic approach would be to increase the maxima by say 2 %points net.

Assuming the beneficial transient effect is real then the maximum for the oil non-condensing boilers can be raised by 2% to 93% net.

The same argument would not apply to the part load condensing maximum efficiency as this is derived from assuming a lower flue temperature, so there is no heat wasted that could contribute to the *beneficial transient effect*.

7 Conclusions and recommendations

Data from the Boiler Efficiency Database indicates that the average difference between full and part load efficiency is positive (i.e. part load is lower) for gas non-condensing non-modulating boilers and negative for oil boilers. A mechanism (the beneficial transient effect) has been identified as a possible explanation for the difference (see part 3 mechanism 6).

Using the average differences in efficiencies in the database the average magnitude of the beneficial transient effect has been estimated.

The impact on the SEDBUK coefficients for oil and the maximum permitted values for non-condensing oil were derived.

Assuming the beneficial transient effect is as estimated from the boiler database efficiency differences, then changes to the SEDBUK coefficients from 0 to -1.1 in equation 201 only are required.

The beneficial transient effect would also increase the maximum permitted efficiencies in SEDBUK for oil non-condensing at part load from 91% to 93% net.

It is therefore recommended that for oil boilers the following changes are implemented:

1) Change the coefficient for oil boilers in equation 201 from 0 to -1.1 %points gross. Other coefficients remain unchanged at -2.8 %points gross.

2) The maximum permitted value for oil non-condensing is raised from 91% to 93% net.

8 References

1. Shiret AR and Hayton J, The Development of an in use – boiler efficiency procedure for use with Part L of the UK Building Regulations, GRTC R 2485, BG Technology, September 1998

2. The Government's Standard Assessment Procedure for Energy Rating of Dwellings, 2005 Edition, BRE, October 2005

3. Council Directive 92/42/EEC, Official Journal of the European Communities, 21 May 1992