

## Efficiency tests on domestic gas and oil fired boilers

### Executive Summary

A series of efficiency tests on “off-the-shelf” domestic boilers was carried out for the government’s Market Transformation Programme (MTP) in March 2005 to March 2006. This report provides SEDBUK results calculated from these tests and compares them with manufacturers’ claimed data as presented on the DEFRA Boiler Efficiency Database. Results are given for 13 domestic boilers (10 gas and 3 oil), and their energy performance is also compared to the minimum requirements of the Boiler Efficiency Directive (BED).

Efficiency tests were carried out by two separate test laboratories (referred to as TLA and TLB), under contract to BRE on behalf of MTP, using standard methods and procedures as specified in EN standards. Initially all tests were carried out by test laboratory TLA. Some of the results were found to be unacceptable, and therefore another laboratory TLB was commissioned to re-test 6 of the original gas boilers. Tests at full-load were carried out using both the “direct” method and an independent method based on heat balance. Tests at part-load were carried out using both “direct” (TLB only) and “indirect” methods.

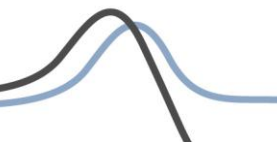
Nearly all MTP test results gave calculated SEDBUK efficiencies lower than shown in the Boiler Efficiency Database (on average over 2% points lower), although the effect of measurement uncertainties must be taken into account. It was also noted that 2 of the 3 oil fired boilers gave efficiencies below the minimum required by the BED, although these results should not be interpreted as indicative of the oil boiler market as a whole.

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## Contents

1	Introduction	3
2	Description of the project	4
2.1	Scope	4
2.2	Boiler efficiency requirements	5
2.3	Independent test method	5
3	Results	6
3.1	Full-load and part-load Efficiency	6
3.2	Calculated SEDBUK Efficiency	8
3.3	Confirmation of full-load efficiency results	11
4	Measurement Uncertainties	13
5	Findings	14
	References	15



## 1 Introduction

This report gives the results from testing thirteen domestic boilers (10 gas condensing and 3 oil non-condensing) in support of the government's Market Transformation Programme. The tests were initially carried out by one test laboratory, but some of the results were unacceptable<sup>1</sup>. Therefore another test laboratory was commissioned to re-test 6 of the original 10 gas boilers. The results were collected to provide comparative data to establish how well the boilers perform relative to the manufacturers' claims and the minimum requirements of the Boiler Efficiency Directive (BED).

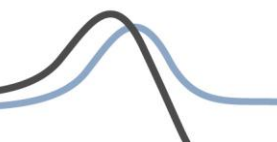
The boilers were tested to the normal EU standards for gas and oil boilers [Ref 2,3,4]. For part-load efficiency (PLE), several methods are allowed and the opportunity has been taken to test each boiler using both "direct" and "indirect" methods. The direct part-load method given in the EU standards allows two different operating modes. Gas condensing boilers were tested using operating Mode No1 (constant return temperature) and oil-fired boilers were tested using operating Model No2 (cyclic mean temperatures).

The full-load efficiency (FLE) was determined on a direct "heat to water" method as given in BS EN standards plus a completely independent method based on heat balance as a comparison.

The efficiency results presented in this report are based on heat inputs calculated on the gross calorific value of the fuel since this is consistent with the way SEDBUK is calculated. To avoid misunderstanding, the original manufacturers' results from the Boiler Efficiency Database are described as "database" and the results completed by the first test laboratory as MTP TLA. The additional tests completed by the second test laboratory are referred to as MTP TLB

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<sup>1</sup> Direct part-load efficiency measurements did not meet all the requirements of BS EN677. Indirect part-load efficiency measurements were excluded for boilers designated 09 and 12 as boiler operating conditions or adjustments were deemed incorrect.



## 2 Description of the project

### 2.1 Scope

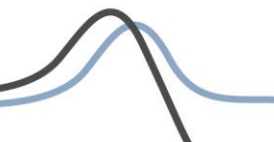
10 gas condensing boilers (6 combi and 4 regular<sup>2</sup>) and 3 oil-fired regular non-condensing boilers were selected for the MTP test programme in March 2005. Gas boilers were chosen so that all major manufacturers were included and some others were included based on an estimate of market share. No detailed market data information was available and therefore the products selected may not necessarily be those most commonly sold. Two of the oil-fired boilers were provided by Northern Ireland Trading Standards Service. The number of oil boilers tested was too small to represent the market, and results must not be interpreted as indicative of the oil boiler market as a whole.

The samples chosen are designated 04 to 13 (gas boilers), and 01, 02 and 03 (oil boilers). All gas boilers and oil boiler No 03 were purchased anonymously from merchants and are assumed to be typical production units offered for sale.

Table 1 shows boiler fuel, type and heat input rating.

<b>Boiler</b>	<b>Type</b>	<b>Manufacturers Heat output at 80/60°C  (kW)</b>
01 - oil	regular	26.4
02 - oil	regular	26.4
03 - oil	regular	26.4
04 - gas	combi	18.0
05 - gas	combi	23.8
06 - gas	combi	18.4
07 - gas	combi	27.2
08 - gas	combi	24.0
09 - gas	regular	15.2
10 - gas	regular	15.0
11 - gas	combi	28.3
12 - gas	regular	18.2
13 - gas	regular	24.7

<sup>2</sup> Regular boilers are "heat only".



The boilers were tested to the normal EU standards for gas and oil boilers. In the case of modulating gas boilers, where it may be necessary to interfere with the normal control arrangements to achieve stability in the part-load efficiency test, manufacturers were invited to state how this had been done in the tests originally undertaken for BED compliance and, if they so wished, to send a technical representative to advise on and witness the test carried out for MTP.

## 2.2 Boiler efficiency requirements

The requirements of the Boiler Efficiency Directive are that:

For gas condensing boilers:-

*At full-load - efficiency must be  $> 91 + \log P_n$*

*at part-load - efficiency must be  $> 97 + \log P_n$*

For oil non-condensing boilers:-

*At full-load - efficiency must be  $> 84 + 2\log P_n$*

*at -load - efficiency must be  $> 80 + 3\log P_n$*

where  $P_n$  is the rated heat output on a net basis.

It was noted that oil-fired boilers 01 and 02 were not listed on the Boiler Efficiency Database and the manufacturers were unable to provide claimed full and part-load efficiency data.

The methods used to determine full and part-load efficiency are given in European standards (Ref [2],[3],[4]). They allow several methods to be used to determine efficiency. For the purposes of this project, the test laboratory was asked to use both the **direct** and **indirect** methods to determine part-load efficiency.

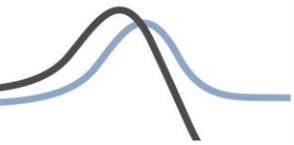
The **direct** method is based on a direct heat-to-water measurement at part-load. The **indirect** method makes use of the measured “standby” heat loss from the boiler and the part-load efficiency is determined by calculation. The SEDBUK efficiency is calculated from an equation of the form:

$$\text{SEDBUK} = (\text{FLE}/2 + \text{PLE}/2) - k$$

The SEDBUK formula specifies that the PLE and FLE are capped if they exceed 85.27% (91% net) and 86.20% (92% net) (for non-condensing oil boilers) and 96.41% (107% net) and 91.00% (101% net) (for condensing gas boilers). This is to ensure experimental uncertainty does not result in unrealistic efficiencies being used to calculate the SEDBUK.

## 2.3 Independent test method

To provide additional confirmation of the boiler efficiency performance, additional tests were completed to determine efficiency using an independent method based on heat-balance. This method does not directly measure the “heat-to-water”: instead it relies on the determination of heat input plus losses from the flue and case and the “heat to water” is determined by difference. (Details of the heat balance method is given in Ref [5]).



## 3 Results

### 3.1 Full-load and part-load Efficiency

Figure 2 shows a comparison of the full-load efficiency results from these MTP tests and the minimum efficiencies as required by the Boiler Efficiency Directive (BED). Figure 3 shows the comparison of part-load efficiency using the **indirect** method as determined by each test laboratory and also as required by the BED. Test laboratory TLA was required to test each boiler at part-load using both direct and indirect methods as given in EU standards. It was subsequently found the direct part-load test results were invalid and therefore have been excluded from this report. Test laboratory TLB completed valid part-load tests, for 5 boilers using the direct method and 6 boilers using the indirect method from the original 10 gas boilers.

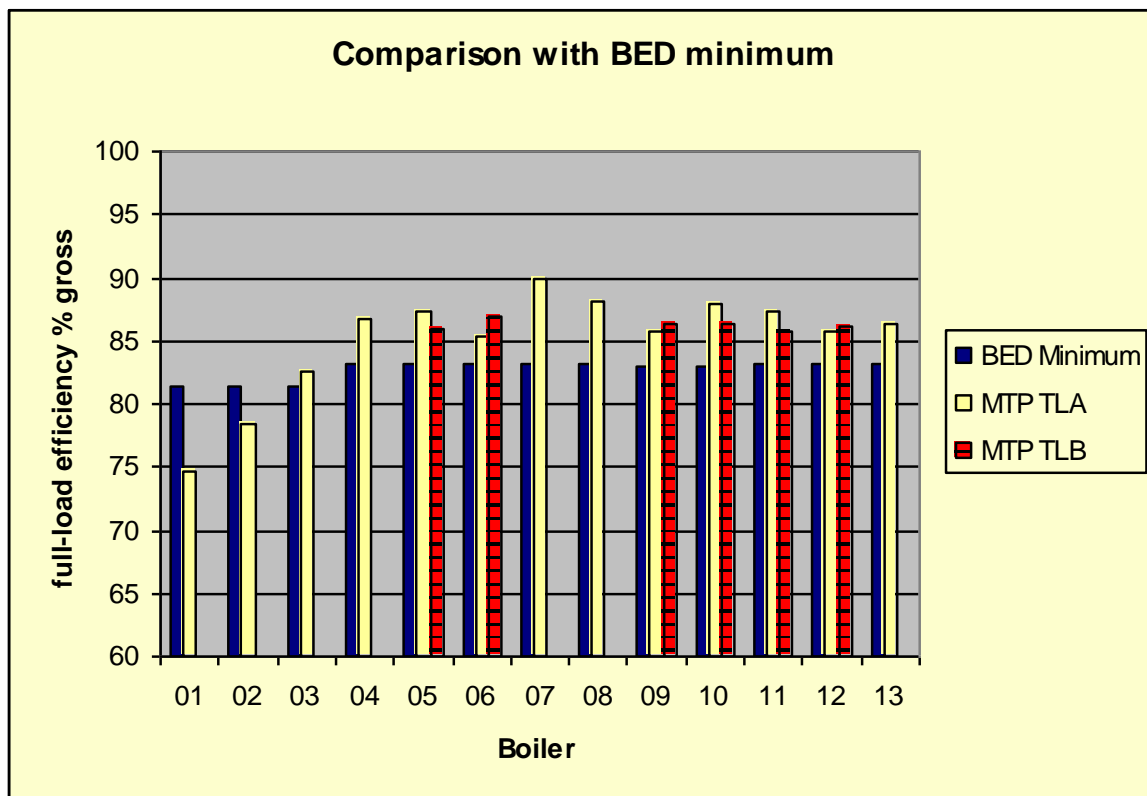


Figure 2 Comparison of full-load efficiency results

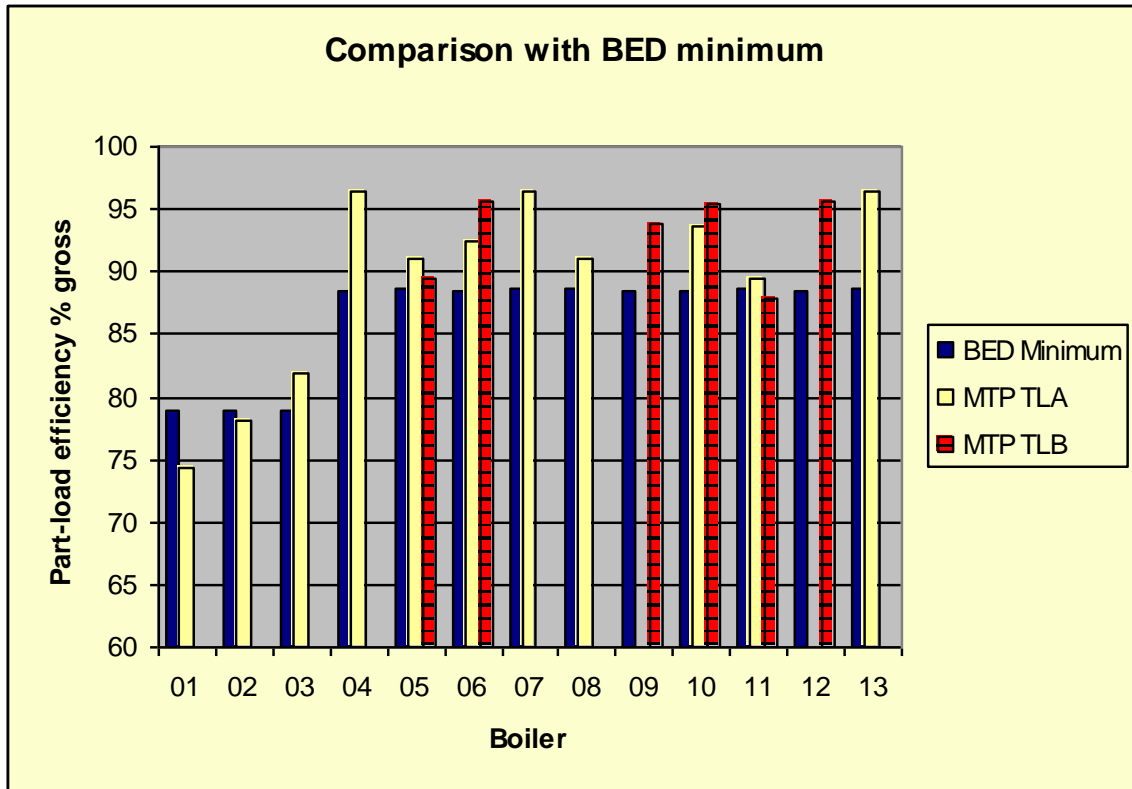
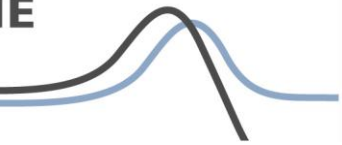


Figure 3 Comparison of part-load (indirect method) efficiency results

MTP results for oil fired boilers 01 and 02 show full and part-load efficiencies below the minimum requirements of the BED. Gas boiler 11 shows part-load efficiencies very close to the minimum required by the BED.

Figure 4 shows a comparison of part-load efficiency data where information from direct and indirect methods is available. (The indirect method was used by test laboratory TLA and both direct and indirect methods used by test laboratory TLB).

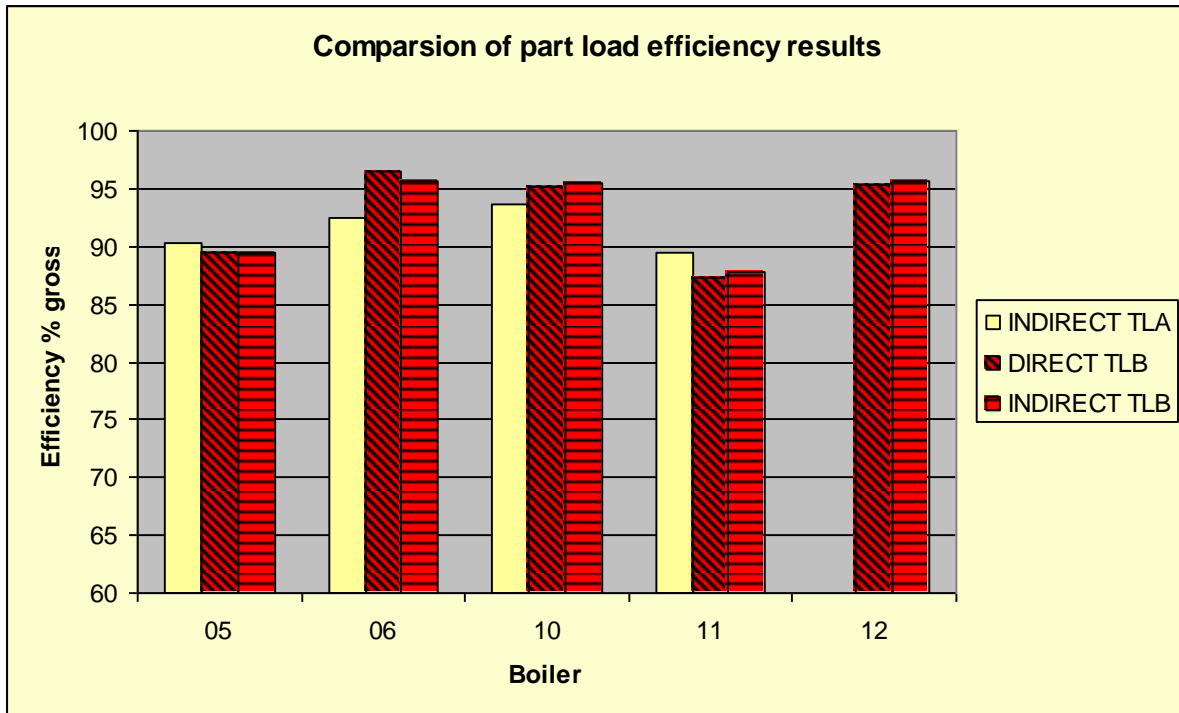
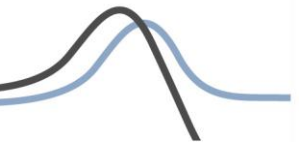


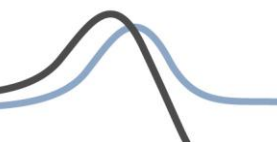
Figure 4 Comparison of all part-load efficiency results

### 3.2 Calculated SEDBUK Efficiency

Table 2 shows efficiencies from the Boiler Efficiency database together with estimated SEDBUK efficiencies based on MTP results from both test laboratories TLA and TLB (also shown in graphical form in Figure 5). Results for test laboratory TLB are shown using part-load efficiency determined by both direct and indirect methods. For boilers 01 and 02, as there are no claimed efficiencies, the minimum efficiencies required by the BED are used to estimate the SEDBUK in place of database efficiency. SEDBUK bands are also shown. In this comparison no account is taken of the measurement uncertainties which are dealt with in section 4.

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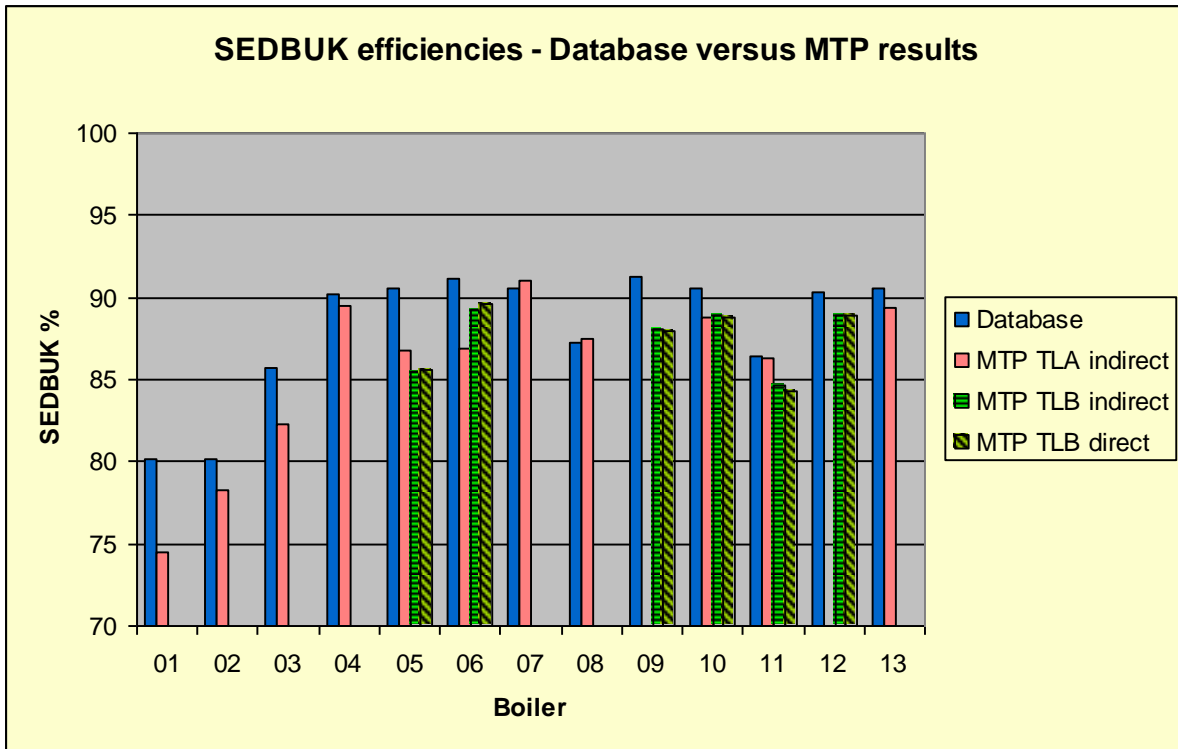
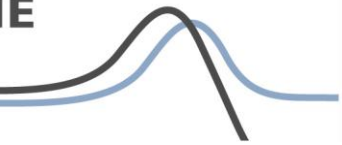


**Table 2 SEDBUK efficiencies**

Boiler	Boiler Efficiency Database		MTP SEDBUK TLA – indirect part load method		MTP SEDBUK TLB – indirect part load method		MTP SEDBUK TLB – direct part load method	
	%	band	%	band	%	band	%	band
<b>1 - oil</b>	80.2*	D	74.5	E				
<b>2 - oil</b>	80.2*	D	78.3	D				
<b>3 - oil</b>	85.7	C	82.3	C				
<b>4 - gas</b>	90.2	A	89.5	B				
<b>5 - gas</b>	90.6	A	86.7	B	85.5	C	85.6	C
<b>6 - gas</b>	91.1	A	86.9	B	89.2	B	89.6	B
<b>7 - gas</b>	90.6	A	91.1	A				
<b>8 - gas</b>	87.3	B	87.5	B				
<b>9 - gas</b>	91.3	A	\$		88.1	B	\$	
<b>10 - gas</b>	90.5	A	88.8	B	88.9	B	88.8	B
<b>11 - gas</b>	86.4	B	86.3	B	84.7	C	84.3	C
<b>12- gas</b>	90.3	A	\$		88.9	B	88.9	B
<b>13 - gas</b>	90.6	A	89.3	B				

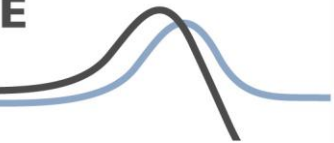
\* Based on minimum efficiency requirement of BED

\$ Data excluded – boiler operating conditions or adjustments were deemed incorrect



**Figure 5 Comparison of SEDBUK results**

Table 3 shows the offset (% points efficiency) for each boiler test result i.e. the amount by which the efficiency results calculated using measurements from MTP tests are **lower** than those given on the boiler efficiency database.



Boiler	Type	% points <b>lower</b> than from Database		
		TLA	TLB	
		Indirect	Indirect	Direct
01 - oil	regular	5.7		
02 - oil	regular	1.9		
03 - oil	regular	3.4		
04 - gas	combi	0.8		
05 - gas	combi	3.9	5.1	5.0
06 - gas	combi	4.2	1.9	1.5
07 - gas	combi	-0.5		
08 - gas	combi	-0.2		
09 - gas	regular	\$	3.2	\$
10 - gas	regular	1.7	1.6	1.7
11 - gas	combi	0.1	1.7	2.1
12 - gas	regular	\$	1.4	1.4
13 - gas	regular	1.3		
<b>mean</b>		2.0	2.5	2.3

\$ Data excluded – boiler operating conditions or adjustments were deemed incorrect

### 3.3 Confirmation of full-load efficiency results

Whereas several test methods can be used to determine part-load efficiency, only one method is specified in the EU standards for full-load efficiency. In order to further assess the full-load efficiency, additional results were obtained using a completely independent method based on a heat balance comparing inputs and losses.

Figure 6 shows a comparison of full-load efficiency at boiler flow return temperatures of 80/60°C using the direct method and the alternative independent heat-balance method.

The MTP results are shown from both test laboratories. All results calculated using the heat balance method are within 2% points of those using the direct, heat-to-water method. Results from test laboratory TLB appear to show very close agreement.

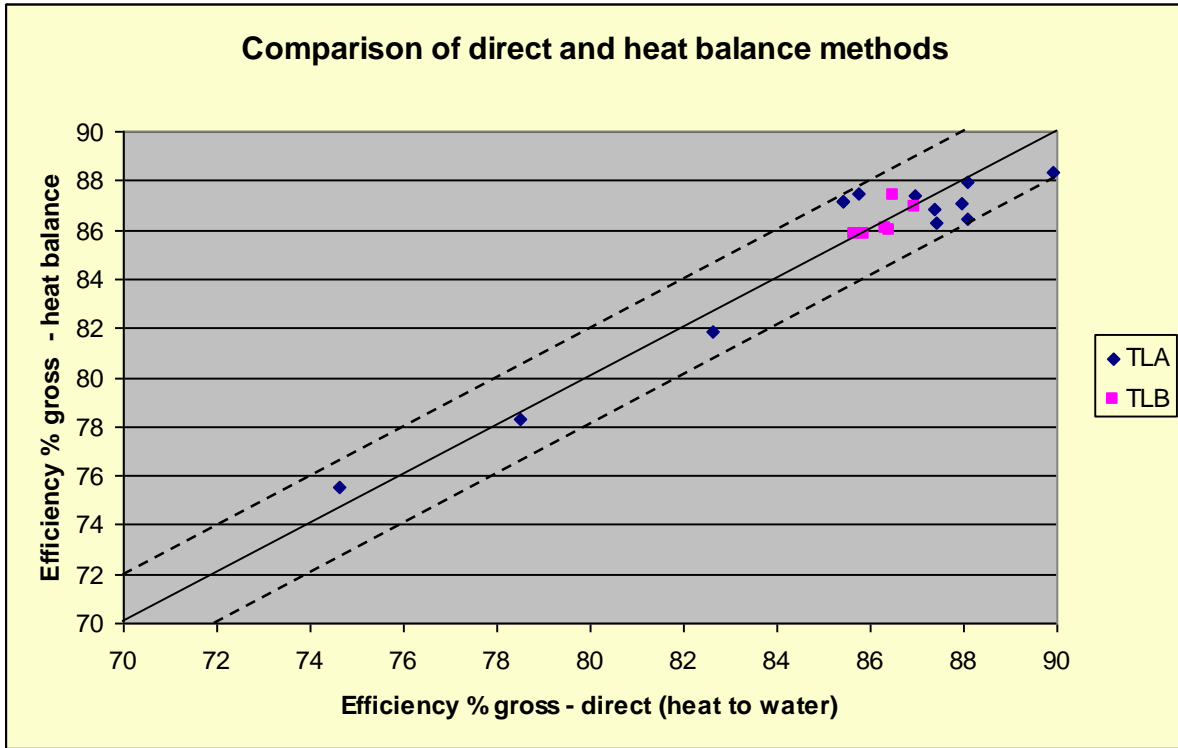
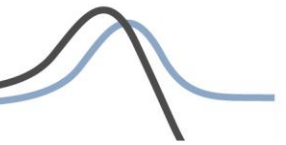
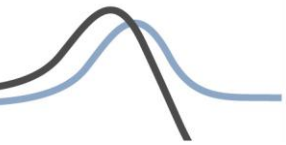


Figure 6 Comparison of full-load results using direct and heat balance methods.



## 4 Measurement Uncertainties

The results obtained confirm the known difficulties in the determination of representative full and part-load efficiencies and its impact of the SEDBUK efficiency.

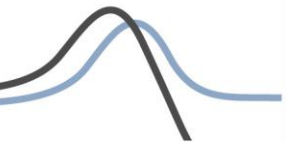
Differences in measured full and part-load efficiencies between those claimed by the manufacturer and obtained from a comparison of this type may be due to:-

- Differences in performance between the off-the-shelf sample boilers used in MTP tests and test samples used by manufacturers as part of their testing for the BED.
- Different methods to determine efficiency as allowed in the standards. i.e. part load by direct and indirect methods.
- Differences in test laboratories:
  - The use of different test rigs and operator techniques.
  - Differences in test rig design and control
  - Differences in test ambient conditions, not all of which may be accounted for as corrections in the calculations.
  - Different interpretation of standards by the test houses.
  - Differences in the use of equipment and the overall uncertainties of the measurement equipment (calibration) and processes.

These factors must be taken into account when interpreting results given in the Boiler Efficiency database. The EU standards indicate that measurement uncertainties should be chosen in a way which ensures total uncertainties in the efficiency measurement of  $\pm 2\%$ . Test laboratory TLB claimed that its total uncertainties for both full and part-load measurements were below  $+2\%$  and TLB provided separate total uncertainties values for all individual tests (less than  $\pm 2\%$ ).

Whilst the  $\pm 2\%$  uncertainty value does not necessarily take account of all the potential differences in test results from test-to-test, boiler to boiler and from laboratory to laboratory, it is evident there is an upward bias when comparing manufacturers claimed results with the MTP results from production, off-the-shelf examples. These results indicate an average upward bias of the SEDBUK efficiency over 2% points.

These results confirm the expected difficulties of comparing results of this type. It can be seen that whilst some differences can be expected and are accepted, there are a small proportion of the boilers tested for which measurement uncertainties alone cannot explain the discrepancy between these MTP test results and manufacturers claims.

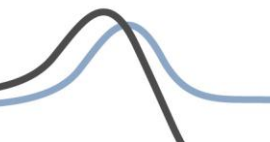


## 5 Findings

- The oil-fired boilers indicated significantly lower (range 1.9 to 5.7% points average 3.7 % points) SEDBUK efficiency results from these tests compared with those on the Boiler Efficiency Database.
- Most gas-fired boilers also indicated lower (range -0.5 to 4.2% points and average 1.4% points (TLA), 2.5% points (TLB) SEDBUK efficiency results from these tests compared with those on the Boiler Efficiency Database.
- Whilst it is evident there are differences in the results from each test laboratory, there is a clear upward bias to the manufacturers results compared to those from these MTP tests. On average, this leads to upward bias in SEDBUK efficiency of over 2% points.
- The two boilers provided by Northern Ireland Trading Standards Service failed to comply with the Boiler Efficiency Directive requirements based on these test results<sup>3</sup>.
- Only a small proportion of gas boilers tested for the MTP programme would retain their current SEDBUK band if based on the results of these tests although this number is extremely sensitive to small differences in efficiency. This aspect should be considered in context since the efficiency data from which SEDBUK is calculated are subject to measurement uncertainties and other factors as outlined in section 4. If the uncertainties value of  $\pm 2\%$  given in the EU standards is taken into account, only one of the gas boilers clearly would not meet its current database band.
- There was good correlation between the full-load efficiency direct (heat to water) and heat balance test results (within 2% points).
- The results from test laboratory TLB show close agreement when direct and indirect part-load efficiency results are compared.

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<sup>3</sup> NITSS pursued this matter with the boiler manufacturers concerned.



## References

- 1 The Government's Standard Assessment Procedure for Energy Rating of Dwellings, 2001 Edition
2. BS EN483:2000 Gas-fired central heating boilers – Type C boilers of nominal heat input not exceeding 70kW.
3. BS EN 677:1998 Gas-fired central heating boilers – Specific requirements for condensing boilers with a nominal heat input not exceeding 70kW.
4. BS EN 304:1992 Heating Boilers – Test code for heating boilers for atomising oil burners.
5. BS 845 – 2:1987 Methods for Assessing thermal performance of boilers for steam, hot water and high temperature heat transfer fluids – Part 2 Comprehensive Procedure.