

## Technical Papers supporting SAP 2009



# Analysis of efficiency tests of water heating by regular and combi boilers

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## Summary

The proposals for the 2009 revision of the Government's Standard Assessment Procedure (SAP) were published for consultation in May 2009 and propose changes to the method of assessment for the energy performance of water heating systems using gas and oil boilers. The relevant proposals include:

- decoupling the efficiency of space heating from the efficiency of water heating
- provision for incorporating water heating test data for gas combi boilers (EN13203:2).

In March 2009 the Department of Environment and Climate Change (DECC) commissioned BRE to organise laboratory tests that were undertaken by Gastec at CRE to:

- measure the energy performance of domestic hot water production from domestic gas combi boilers and from regular boilers connected to a separate hot water cylinder
- examine any consequences for the proposals in SAP 2009 in relation to water heating.

Previous hot water tests (ref 3) that helped inform the SAP proposals were limited to one hot water draw-off schedule (100 litres/day) and combi boilers. The newly commissioned tests covered an additional draw-off schedule (200 litres/day) and regular boiler systems, the latter requiring special test arrangements as they are not covered by the water heating test standard.

This report presents the analysis of the test results, the aim being to:

- compare the energy performance of combi boilers based on two sets of data, or one set of data, with the default case in the SAP proposals
- compare the energy performance of regular boilers as tested with that modelled in the SAP proposals
- compare the energy performance of regular boilers and combi boilers.

Concerning the water heating energy performance, it was concluded that:

- the proposals in SAP represent the water heating energy performance of combi and regular boilers reasonably well
- the combi boiler tested used less gas in its normal mode than when operated as a regular boiler connected to an insulated hot water cylinder
- the combi boiler (28kW) when tested as a regular system (and connected to an insulated hot water cylinder) used more gas than a lower output regular boiler (12kW).

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## 1 Introduction

The Department of Environment and Climate Change (DECC) commissioned BRE to arrange and analyse laboratory tests on boilers that were undertaken by Gastec at CRE (ref 1). The tests measured the energy performance of boilers when being used for domestic hot water production alone (not space heating). A domestic gas combi and gas regular boiler were tested. The aims of the tests were:

- to evaluate the performance of a combi and a regular boiler for several draw-off schedules
- to test the proposals in the 2009 revision of the Government's Standard Assessment Procedure (SAP) for energy rating of dwellings (ref 2) regarding the provision for accepting water heating test data for combi boilers (standard EN13203:2), and the impact on the proposals of the relative performance between combi and regular boilers.

Previous hot water tests commissioned by BRE (ref 3) examined one draw-off schedule (100 litres/day) with combi boilers. The tests here include:

- testing under a larger draw-off schedule
- operating a combi boiler (28kW) as if it were a regular boiler
- testing a lower output regular boiler (12kW).

This report specifically analyses the test data to:

- i) Compare the default case (no hot water data provided) for combi boilers in SAP against the case where hot water test data is provided, and so determine whether there is an inducement for manufacturers to provide additional test data.
- ii) Assess the comparative performance of regular and combi boilers in the laboratory, and consider whether this is reflected adequately in the SAP 2009 proposals.

## 2 SAP 2009 proposals

The SAP 2009 proposals, sent out for public consultation in May 2009, make provision for manufacturers to submit hot water test data based on one or two hot water draw-off schedules under the test standard (EN13202:2). The test data required is: useful heat drawn-off (kJ per day), net efficiency (%), total daily and useful daily volume of water (in litres). The data is used to derive three parameters for potential use in SAP 2009:

- a) a water heating efficiency (gross calorific basis)
- b) a constant amount of heat required irrespective of draw-off volume, to account for storage heat loss or the extra heat required to operate a keep-hot facility in a combi
- c) the proportion of heat rejected because the hot water is not warm enough.

The SAP 2009 proposals also separate the summer and winter boiler efficiency for both combi and regular boilers, moving away from the single annual efficiency used previously.

Care must be taken when comparing test and SAP efficiencies because there are two different definitions of water heating efficiency. The usual definition for the production of hot water efficiency and that used in the European Standards is:

$$\eta_{\text{DHW}} = \frac{\text{heat content of the useful hot water drawn}}{\text{heat in fuel consumption (net basis)}}$$

In SAP the efficiency is calculated by adding the heat content of hot water required and the heat required to keep any stored water hot, and then dividing by the total heat of the fuel to get the water heating efficiency. The definition of water heating efficiency in SAP is:

$$\eta_{\text{SAP}} = \frac{\text{heat content of the useful hot water drawn} + \text{heat generated to keep stored water hot}}{\text{heat in fuel consumption (gross basis)}}$$

If SAP were to calculate the consumption by dividing the heat content of hot water required in total by the usual DHW efficiency, it would be assuming the efficiency is independent of hot water volume. This would be an incorrect assumption when stored hot water losses are present; hence the alternative approach.

To distinguish between the two different efficiencies in this report the first is called the measured *domestic hot water* (DHW) efficiency and the latter the *SAP water heating* efficiency.

### 3 Tests undertaken

The following hot water efficiency tests were undertaken at GASTEC at CRE (ref 1):

- a) EN13203:2 hot water schedule 2 and 3: condensing instantaneous combi boiler (28kW output) with the keep-hot facility inactive
- b) EN13203:2 hot water schedule 2 and 3: condensing instantaneous combi boiler (28kW output) with the keep-hot facility active
- c) EN13203:2 hot water schedule 2 and 3: condensing instantaneous combi boiler (28kW) with keep-hot facility inactive connected to a standard 120 litre hot water cylinder conforming to BS 1566, reference 7, type G, with primary pipework 1.5 metres long and insulated to the levels recommended by Approved Document L of the Building Regulations. This test is also referred to as a “large condensing regular equivalent” in this document.
- d) EN13203:2 hot water schedule 2 and 3: condensing regular boiler (12kW) connected to a standard 120 litre hot water cylinder conforming to BS 1566, reference 7, type G, with the same insulated primary pipework as above.

Tests a), b) and c) were carried out using the same boiler and are used to compare regular versus combi operation for the same boiler. The boiler in test d) is less powerful but more typical of a regular boiler. Both boilers used in all four tests were obtained “off-the-shelf”; ie bought from merchants in the usual supply chain.

Tests a) and b) did not involve substantial amounts of stored hot water (less than 15 litres) so tests were conducted over one day as recommended by the standard (EN13202:2).

Tests c) and d) required the boilers to be connected to a standard insulated 120 litre hot water storage cylinder, which has a substantial thermal capacity. Specially adapted tests based on the EN13203:2 test schedules number 2 and 3 were undertaken, both for a small (12kW) and large (28kW) boiler. The tests followed the relevant part of the PAS 67 (ref 4) hot water test method, originally designed for testing the water heating performance of micro-cogen packages. The method requires an estimate of the energy content of the hot water store at the start and end of each 24-hour period in the test. This is important because changes in the heat content of the store during the test may be large by comparison with the heat content of the water drawn off, and large errors will occur in the calculated efficiency unless they are taken into account. A further measure to reduce the effect of such changes was to repeat the test schedule over two consecutive days (three days in total). Measurements of the cylinder’s vertical temperature profile by seven thin film temperature resistance devices in positions specified by clause 10.4.2.2 of PAS 67 were taken to allow the magnitude of the changes in the stored energy to be calculated. The cylinder was heated continuously under cylinder thermostat control.

## 4 Test results

The results from the tests required are shown in Table 1. According to the proposals in SAP 2009, these can be used in the assessments for combi boilers. The parameters derived from the test results and used in the SAP proposals are given Table 2. Table 3 shows the case when no optional data is provided. All efficiencies quoted are on a net calorific basis.

**Table 1: Summary of test results**

Test arrangement				Schedule No 2			Schedule No 3		
Boiler	Keep-hot status	Hot water tank	Rejected energy	Heat drawn off (KJ)	DHW efficiency <sup>1</sup> % net	Rejected energy	Heat drawn off (KJ)	DHW efficiency <sup>1</sup> % net	
A	Combi	inactive	No	0.15%	20850	81.7	0.10%	43245	85.9
B	Combi	active	No	0.05%	20897	76.9	0.05%	43457	83.1
C	Combi	inactive	Yes	0%	21495	57.2	0%	42854	67.8
D	Regular	inactive	Yes	0%	21928	64.6	0%	42958	71.6

**Table 2: SAP hot water parameters derived from test data**

Test arrangement			Schedule No 2 only			Schedule No 2 and No 3		
Boiler	Keep-hot status	Hot water tank	SAP Water heating efficiency <sup>1</sup> % net	Constant amount kWh/day	Rejected energy	SAP Water heating efficiency <sup>1</sup> % net	Constant amount kWh/day	Rejected energy
Combi	inactive	No	<b>99.9</b>	<b>1.28</b>	0.05%	<b>90.2</b>	<b>0.528</b>	0.075%
Combi	active	No	<b>99.9</b>	<b>1.73</b>	0.05%	<b>89.8</b>	<b>0.777</b>	0.05%
Combi	inactive	Yes	<b>99.9</b>	<b>4.47</b>	0%	<b>83.4</b>	<b>1.622</b>	0%
Regular	inactive	Yes	<b>97.4</b>	<b>3.09</b>	0%	<b>80.6</b>	<b>1.099</b>	0%

**Table 3: SAP hot water parameters in the absence of hot water test data**

Boiler arrangement			Case when no EN13203 provided		
Boiler	Keep-hot status	Hot water tank	SAP Water heating efficiency <sup>1</sup> % net†	Constant amount kWh/day	Rejected energy
Combi	active	No	<b>87.8</b>	<b>1.644</b>	0%
Combi	inactive	No	<b>87.9</b>	<b>1.644</b>	0%
Regular	inactive	Yes	<b>87.8</b>	<b>2.290</b>	0%

† derived directly from the full load test data for the Boiler Efficiency Directive, including adjustments as documented in B2, SAP 2009 proposals (ref 2)

The test efficiencies (Table 1) with a hot water tank fitted are the average of the last two days of data and include a minor adjustment due to the different storage temperatures at the end and start of the two days.

<sup>1</sup> *DHW* and *water heating* efficiency are not the same (see section 2).

As noted in section 2, it is vital to realise that measured DHW efficiency (in Table 1) is not the same as the water heating efficiency needed for SAP (in Table 2), even though in the Tables here both have been quoted on a net calorific value basis for comparison. The measured DHW efficiency is considerably lower because it discounts any heat emitted from stored hot water or that used by a keep-hot facility, whereas the SAP water heating efficiency is higher because it counts them as potentially useful; they are subtracted explicitly as a constant value (i.e. independent of water volume). The approach in SAP allows for any beneficial heat gains from the storage or combi heat losses to be included in terms of reducing space heating demand.

#### **4.1 Gas consumption results**

Figure 1 shows the daily gas consumption in the summer months as estimated by the SAP 2009 proposal. It shows EN13203 test results using schedule 2 alone (dotted lines), using both schedules 2 and 3 (solid coloured lines), and results from tests as a regular boiler with cylinder (solid black and grey).

The daily consumption for the summer months is shown as a function of hot water usage warmed by 37K; the annual average assumed in the SAP 2009 proposals.

The vertical lines (schedules 2 and 3) show the equivalent daily volumes of 100 and 200 litres raised by 50K with the same amount of energy. The 50K rise is the usual way that volumes are quoted in EN13202:2.

The regular boilers with EN13203:2 test data are only hypothetically applied to the proposals in SAP, as there are no standards for testing regular boilers in hot water mode and hence no provision for adding test data. These results are included specifically to show how a regular system compares with a combi system when tested.



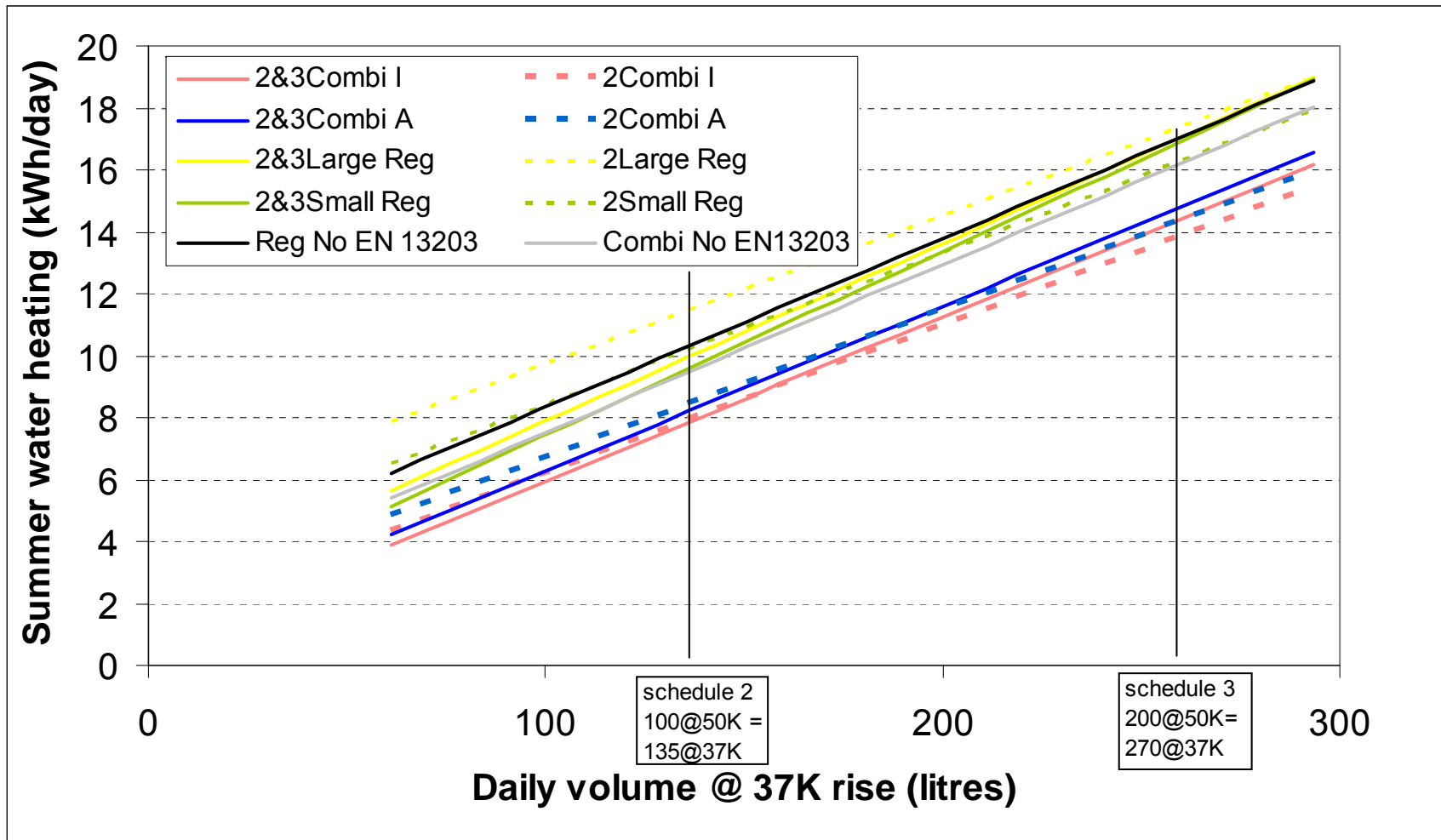


Figure 1 – Gas consumption for water heating for various boiler and test sets

#### 4.1.1 Comparison of testing with two schedules against one or none

The red and blue *dotted* lines show the estimated consumption in SAP when only test schedule 2 data is included, and the red and blue *solid* lines when both test schedule 2 and 3 data is included. The figure shows the dotted lines are generally higher than the corresponding coloured solid lines, which means that the consumptions estimated by SAP are higher when based on one schedule than those based on two schedules. This is desirable as it is an incentive to provide more data and obtain more realistic results. The exception is for the combi lines above 200 litres, but here they are still close.

#### 4.1.2 Regular boiler

The small regular boiler (green solid line) has marginally better performance than the large regular arrangement (yellow solid line), converging at higher water usage.

The solid black line (regular boiler as proposed in SAP 2009) is higher than the green solid line (regular boiler as if hot water test data were to be used in SAP 2009 based on two draw-off schedules). This indicates that the proposals for regular boilers in proposed SAP 2009 would result in the summer water heating consumptions being 20% lower at low water usage and the same at high water usage. Overall this is considered a reasonable compromise.

#### 4.1.3 Comparison of combi versus regular boilers

Comparing the yellow solid line (combi used as a regular boiler) against the red and blue solid line (combi with and without the keep-hot active) shows a combi arrangement is better in terms of energy consumption than the regular arrangement.

Comparing the yellow and green solid lines (combi in regular mode against smaller regular boiler) shows the large regular system is slightly worse than the small regular, as expected. The gas used in the tests for the smaller system is as much as 10% less than that used for the larger system. The small regular boiler (green solid line) has higher gas consumption than combi boilers in combi mode (red and blue solid lines).

The gas consumption of the regular systems is somewhat higher than the combi boilers. This is confirmed by the test results that show:

- gas used in the tests for the combi boilers (in combi mode) is between 18% and 30% less than the gas used for the combi boiler in regular mode (the higher figure is for schedule 2 and the lower for schedule 3).
- gas used in the tests for the combi boilers is between 14% and 21% less than the gas used for the small regular boiler (the higher figure is for schedule 3 and the lower for schedule 2).

## 4.2 Electricity consumption

Table 4 shows the daily electricity consumption during the tests.

Table 4 Electrical hot water test data

System	Keep-hot status	Hot water cylinder	Schedule	KJ/day	KWh/year
Combi	active	No	No 2	886	90
Combi	active	No	No 3	1102	112
Combi	Inactive	No	No 2	641	65
Combi	Inactive	No	No 3	853	87
Combi	Inactive	Yes	No 2	873	89
Combi	Inactive	Yes	No 3	1062	108
Regular	N/A	Yes	No 2	1075	109
Regular	N/A	Yes	No 3	1256	127

In SAP, 175 kWh per year is attributed to the central heating circulator and a boiler fan.

All the test consumptions are lower than the SAP assumed consumption that is linked to both space and water heating, which is not surprising given the test values are only concerned with water heating. Given the results are concerned only with water heating, the SAP value looks on the low side. It is impossible to estimate by how much, as some of the electricity used will be common to both space and water heating (eg, circuitry, programmer power etc) and some will be dependent on the space heating load (eg, circulator power duration) and some will be dependent on the switching between water and space heating operation (eg, motorised valves).

## 5 Conclusions

### 5.1 Impact on the quantity of test data included in an assessment

The proposals in SAP 2009 (ref 2) make provision for the first time for inclusion of hot water efficiency test results for combi boilers when carrying out an energy assessment. The proposals include the three options:

- a) An assessment based on no hot water test data (default case)
- b) An assessment based on the standard results: EN13203:2 schedule number 2
- c) An assessment based on the standard results: EN13203:2 schedule number 2 plus number 3 schedule.

It was found that:

- using results from two water heating performance test schedules produces generally lower gas consumption for hot water than those using one test schedule
- the consumptions using only one schedule produces lower consumptions than the default case.

This will encourage the provision of water heating test data from manufacturers.

### 5.2 Regular boiler performance

The provision for inclusion of water testing test data only applies to combi boilers because there is no equivalent standard for regular boilers. Here, however, tests were made in conjunction with a hot water cylinder as described in section 3. The performance of the smaller boiler was marginally better at low water volumes and the same at high water volumes.

The proposed treatment in SAP of regular boilers predicts the same summer water heating consumption as the test results at high water volumes but slightly worse at low water volumes. The difference in summer water heating fuel consumption varies between 0 to 20%. Overall, this is considered a reasonable agreement, bearing in mind other uncertainties about primary pipework and cylinder heat loss assumed by SAP.

### 5.3 Regular boiler versus combi boiler performance

In terms of summer water heating, regular boilers when tested under EN13203:2 use more fuel than combi boilers. But in the main this is not due to the difference in boiler performance, because further tests with the same combi boiler set up as if it were a regular boiler also showed that the regular arrangement used more fuel than the combi with directly supplied hot water. As expected, the combi in regular mode (28kW) used more fuel than a smaller regular boiler (12kW), which in turn used more than the combi boiler alone.

#### **5.4 Overall**

It is concluded that the SAP 2009 proposals concerning boilers are reasonable for regular and combi boilers, and provide incentives to manufacturers to supply hot water efficiency data rather than rely on default assumptions.

- 11 Analysis of efficiency tests of water heating by regular and combi boilers

## 6 References

- 1 Hot Water Performance of a Condensing Combination and System Boiler, GASTEC at CRE, Report, Number 221098, March 2009
- 2 The Government's Standards Assessment Procedure for Energy Rating of Dwellings, SAP 2009 proposals, BRE, April 2009
- 3 Shiret A, STP09/B04 Analysis of results from energy performance tests on combi boilers, BRE, March 2009
- 4 Publicly Available Standard 67 (PAS-67), Laboratory tests to determine the heating and electrical performance of heat-led micro-cogeneration packages primarily intended for heating dwellings, BSI, 2008.