Wet Central Heating Systems: Treatment of Heat Transfer Modifiers, Inhibitors, Flushing Techniques and Inline Cleaners in the National Calculation Methodology for Energy Rating of Dwellings (SAP)

The UK Government's Standard Assessment Procedure for Energy Rating of Dwellings (SAP), including reduced data SAP (RdSAP), is the UK's National Calculation Methodology (NCM) for energy rating of dwellings. To assess a dwelling's energy performance data is needed that describes the installed construction components and building services equipment. Such data is either generic, determined by the materials and type of product ("type data") or specific, where validated individual branded product performance data has been made available ("product data").

This paper explains the treatment of the following wet central heating system products in SAP:

- Heat Transfer Modifiers - These alter the thermal characteristics of primary water and could be an additive or device
- Inhibitors (for both space heating and hot water systems)
- Flushing Techniques
- Inline Cleaners/Filters

The paper first considers the treatment of Inhibitors, Flushing Techniques and Inline Cleaners/Filters in SAP and presents reasons why recognition is not possible. The paper then considers Heat Transfer Modifiers, where the technical basis for determining efficacy is defined in a test programme in conjunction with statistical significance rules. Only if efficacy can be demonstrated in accordance with this paper would SAP recognition be considered.

Inhibitors, Flushing Techniques and Inline Cleaners/Filters

SAP is an asset rating tool for the comparison of dwellings and assumes standardised heating and hot water requirements. SAP assumes dwellings are constructed correctly in accordance with the design and that building services are installed and maintained competently in accordance with established good practice.

The Building Regulations 2010 - Part L1A supporting document: 'Domestic Building Services Compliance Guide – 2010 Edition' states that 'central heating systems should be thoroughly cleaned and flushed before installing a new boiler'. It also states that 'a chemical water treatment inhibitor meeting the manufacturer's specification or other appropriate standard should be added to the primary circuit to control corrosion and the formation of scale and sludge'. The effect of system sludge upon heat emitter effectiveness has been the subject of a study conducted by Kiwa UK Ltd. entitled *'Final report on efficiency effects of addition of "sludge" to a boiler and radiator system & subsequent cleaning options & efficiency effects'*. This report showed that the build-up of solid material (sludge) within a heat emitter system can reduce the ability of the system to deliver heat and potentially impact boiler efficiency.

Boiler manufacturers typically include cleaning and flushing as requirements within installation and commissioning manuals for warranty validity. In the case of hot water heating systems, the Compliance Guide also makes recommendations regarding the treatment of incoming cold water when the total water hardness exceeds 200 parts per million.

In summary, flushing of wet heating systems and the addition of Inhibitors during new boiler installation or boiler replacement are recommended minimum standards in the Compliance Guide, and omission of these may be considered a Building Regulations compliance failure.

The installation of Inline Cleaners/Filters may or may not be considered good practice, but any effect upon scale and sludge formation that these may have cannot be recognised within SAP due to the principles defined above.

Heat Transfer Modifiers

Anecdotal evidence and field trials are not satisfactorily robust to derive conclusions on the effect of Heat Transfer Modifiers. There are many factors that cause the fuel consumption of heating systems to differ, the main ones being variation in the amount of useful heat produced and the temperature conditions under which the boiler operates. Without precise measurements of the calorific energy content of the fuel consumed, useful heat output and water temperature differential, no conclusions can be drawn that a change in fuel consumption is caused by a Heat Transfer Modifier. In practice these measurements can only be taken accurately in laboratory conditions.

The prospect for saving energy relies on two phenomena:

(i) If, other conditions being equal, the heat transferred to water within a boiler is increased then more of the heat produced by combustion is useful and less is wasted in flue gases. The efficiency of the boiler, defined as useful heat output divided by the calorific energy of the fuel consumed, is thereby raised. When efficiency is raised the amount of fuel required to provide heating and hot water service to a given standard is reduced.

(ii) If, other conditions being equal, the heat transferred from water to air by a radiator is increased then more of the heat in the water circuit of the heating system is extracted and less is returned to the boiler. This has a small influence upon the efficiency of the heating system insofar as a lower return water temperature raises boiler efficiency slightly. The effect is the same as if the radiator had been a larger size. However, a considerable increase in heat emission is necessary to produce a small improvement in boiler efficiency, and the operating conditions of the heating system have to be adjusted by means of suitable controls to exploit the effect.

In order to demonstrate that a Heat Transfer Modifier saves energy in relation to the two phenomena stated above, a number of laboratory tests are recommended. They should be designed to show:

- Effect on boiler efficiency under full-load conditions, as measured in standard EN tests
- Effect on boiler efficiency under part-load conditions, as measured in standard EN tests
- Variation with water temperature
- For instantaneous combination boilers, the effect on hot water service
- Variation with different heat exchanger materials (aluminium, stainless steel, mild steel)
- Variation with boiler types (notably oil boilers)
- Variation with age of boiler
- Durability (variation of the effect with time)
- Variation with dilution rate (if applicable)

To minimise testing costs it is recommended that a phased approach is taken, carrying out the most important tests first. Only if results from the first phase are judged to be successful is it worthwhile proceeding to subsequent phases.

A recommended test programme to investigate the effect on boiler efficiency is set out in Appendix A, with details of the schedule of tests and test procedures presented in Appendices B and C respectively.

In addition, the factors below must be investigated to ensure that the Heat Transfer Modifier has no significant adverse effects that would impede commercial success:

- Implications for maintenance (feasibility of regular “top-up” in a domestic context, if applicable)
- Long-term effect on materials that the Heat Transfer Modifier contacts
- Confirmation that manufacturers of boilers (and other system components) will not repudiate a guarantee for their products in systems where a Heat Transfer Modifier is in place
- Confirmation of low risk levels in regard to environment, health, corrosion, chemical hazard, and the sewerage system (if applicable).

Appendix A – Recommended Test Programme

A number of tests will be required to confirm that the heating system Heat Transfer Modifier provides a benefit under conditions typically encountered within a domestic heating system. It is preferable to conduct any test programme in two phases, so that further costs are avoided if Phase 1 results are found unsatisfactory after analysis.

The full-load efficiency tests described for Phase 1 are required to prove the potential of the Heat Transfer Modifier and confirm that further testing is worthwhile. The tests are described for a gas boiler, and additional tests following the same principles will be needed with an oil boiler if it is desired to investigate benefits for oil-fired systems too. The additional tests in Phase 2 will be required to estimate energy savings for potential SAP recognition.

Laboratory tests – Phase 1

Phase 1 tests are recommended to examine performance under conditions of high heat demand, when the boiler is called upon to produce water at a relatively high temperature. The test schedule is defined in Appendix B and the laboratory procedure in Appendix C. Laboratory tests are subject to measurement uncertainty and therefore care must be taken to ensure that differences between test results are statistically meaningful. Appendix D defines a specification to determine the statistical significance of test results.

Phase 1 tests should be carried out using a modern gas condensing boiler. The basic method of assessment is to compare the measured thermal efficiency at full-load, and when operating under controlled laboratory conditions, with and without the Heat Transfer Modifier installed. All heat inputs, outputs and losses would be measured so that the heat balance can be quantified.

Laboratory tests – Phase 2

If, after analysis, the results of Phase 1 are satisfactory, further tests should be specified in accordance with the test schedule set out in Appendix B and the laboratory procedure in Appendix C, with reference to statistical significance parameters defined in Appendix D:

- Part-load efficiency: These are similar to the tests in Phase 1 and subject to the same EN standards. Results will be used together with those from the full-load tests to estimate impact on in-use efficiency.
- Full-load efficiency at low temperatures: Similar tests to those in Phase 1 should be conducted at flow/return temperatures of 50/30°C to assess the Heat Transfer Modifier's sensitivity to temperature.
- Hot water draw-off (for combination boilers only): These tests assess whether an energy saving benefit also applies to domestic hot water. The test is in accordance with EN13203-2.
- Effect on other boiler materials: Phase 1 tests should be undertaken on a gas boiler with an aluminium heat exchanger. Stainless steel is the second most common material for the heat exchangers of gas condensing boilers and mild steel is used in oil boilers. The Heat Transfer Modifier, if an additive, may behave differently when in contact with these alternative materials.

- Effect on oil-fired boilers: Oil-fired boilers are constructed of different materials and usually operate with on/off rather than modulation burner control. They are, however, a much smaller sector of the boiler market.
- Effect on older boilers: The performance of the Heat Transfer Modifier may be affected by an accumulation of oxides and scale on the waterside surface of a boiler heat exchanger. This can be established by testing on boilers that have previously been in service for some years within a hard water area.
- Lifetime: The durability of the Heat Transfer Modifier's effect should be determined. Long-term tests should be devised to see whether the energy saving benefit diminishes over time, and whether it needs replacement or top-up at regular intervals to maintain effect.
- Effect of additive dilution: The reducing effect of Heat Transfer Modifier, if an additive, as dilution increases should be investigated, bearing in mind that the water in central heating systems is gradually replaced.

Appendix B – Schedule of tests (Phase 1)

The schedule of tests is shown in Table 1; these are full-load boiler efficiency tests as specified in Appendix C.

The tests must be undertaken in the order shown and with reference to the following:

- Day 1 must not be the beginning of the working week (i.e. not Monday or the day after a Public Holiday)
- Days 1 and 2 must be consecutive
- The same operator(s) must be used for all tests
- The person(s) doing the tests should not know the results of the previous tests.

Test number	Time	Test Description	Scenario
1	Day 1 – Start early morning	Start from cold and measure over four 30-minute periods once equilibrium is reached.	Plain water, Heat Transfer Modifier not used
2	Day 1 – Start early afternoon	Start from cold and measure over four 30-minute periods once equilibrium is reached.	Water treated with Heat Transfer Modifier (to manufacturer's specification)
3	Day 2 – Start early morning	Start from cold and measure over four 30-minute periods once equilibrium is reached.	Water treated with Heat Transfer Modifier (to manufacturer's specification)
Boiler and test rig system cleaned and flushed thoroughly to remove primary water and Heat Transfer Modifier, if applicable[1]			
4	Day 3 – Start early afternoon	Start from cold and measure over four 30-minute periods once equilibrium is reached.	Plain water, Heat Transfer Modifier not used

Table 1: Test schedule

[1] Between test numbers 3 and 4 it is necessary to remove all traces of the Heat Transfer Modifier, if an additive, and primary water from the boiler and test rig system. Due to the nature of heating system additives, this will require the use of a specialised cleaning solution and repeated flushing. Therefore, time has been provided between days 2 and 3 for cleaning to be undertaken.

Appendix C – Laboratory test procedure (Phase 1)

General requirements

The tests are full-load gas boiler efficiency tests undertaken in accordance with the procedure defined in EN677 and the relevant requirements of EN297, EN483 and EN625. The following additional conditions apply to Phase 1 testing:

a) Tests should be undertaken by an independent laboratory using a suitable test rig capable of full and part-load boiler efficiency testing. The rig must be capable of undertaking part-load testing by the “direct method” using “operating Mode No 1” as given in EN483.The part-load capability is required from the outset to maintain consistency with later tests.

b) The independent laboratory must use a registered Quality Management System when undertaking boiler testing. All measurement equipment used in testing must be calibrated by an accredited UKAS laboratory (or equivalent); otherwise the calibration must be traceable back to national standards. Appropriate quality assurance procedures must be used to verify or cross-check the accuracy and repeatability of the test procedure and test results.

c) The boiler selected for use on the test rig should be a typical new gas combination boiler on sale in the UK market with an input rating not exceeding 30kW. It should be a market-leading product from a well-known manufacturer. It should have an aluminium heat exchanger and a modulating burner capable of operating continuously down to at least 30% of its nominal heat input. The Building Research Establishment (BRE) can advise on suitable makes and models on request.

d) The boiler should be operated using G20 test gas throughout.

e) The primary water flow through the boiler should be adjusted to give a flow temperature of 80°C and a return temperature of 60°C within the tolerances given in the standard referred to above. Once this flow rate has been set it should be maintained for all subsequent full-load tests.

f) A schedule covering the number of tests with and without a Heat Transfer Modifier has been prepared and is specified in Table 1 of Appendix B. This is required to obtain statistically significant results. Table 1 shows the proposed test programme over 3 days. If this programme presents any difficulties to the test laboratory, they should agree a revised programme with BRE before work starts.

g) Each full-load test should start from cold and once thermal equilibrium[2] is reached three 10-minute measurements should be recorded. This 30-minute test period constitutes a separate independent measurement. Four 30-minute test periods are required for each test number.

[2] The boiler is considered to be in thermal equilibrium when the efficiency measurement of three consecutive cycles, combining any two results from three, does not vary by more than 0.5% (see page 92, EN483:1999+A4:2007).

h) Between test numbers 3 and 4 it is necessary to remove all traces of the Heat Transfer Modifier and primary water from the boiler and test rig system. Due to the nature of Heat Transfer Modifiers, if an additive, this will require the use of a specialised cleaning solution and repeated flushing. If this presents any difficulties to the test laboratory, they should discuss with BRE before work starts.

i) In addition to measurements required by the standards for boiler efficiency, further measurements shall be made during tests to allow an energy balance validation (EBV) to be carried out for each full-load test result. The EBV method produces a “residual” which indicates any imbalance in the measurement of heat quantities and losses. For these tests a residual value not exceeding 1.0% is required for each 30 minute test period. The additional measurements required are shown in Table 2 below. Further details of the EBV method[3] and the Excel Workbook will be provided on request by BRE.

Test report

The test report should be provided in both paper and electronic form. All results and all data measurements should be provided in an Excel workbook.

The full-load tests should include the data given in Table 2 for each test condition; i.e. each 10-minute cycle. Therefore, for each test number there should be 12 sets of data; i.e. four lots of three consecutive cycles that meet the thermal equilibrium criteria.

Efficiency (net)	%
Net input	kW
Heat output	kW
Flow temperature	^{o}C
Return Temperature	^{o}C
Flue gas temperature	^{o}C
Primary water flow rate	Kg/hour
CO_2 in flue gas	%
Ambient air temperature	^{o}C
Condensate flow rate (assumed to be zero)	Kg/hour
Ambient air humidity	%
Electrical power (including integral pump)	W
Electrical power (excluding integral pump)	W

Table 2 - Data required for each 10-minute full-load efficiency test cycle

[3] STP09/B02, Energy Balance Validation: Investigation of the residual energy of thermal efficiency tests on gas and oil boilers, available at: http://www.bre.co.uk/filelibrary/SAP/2012/STP09-B02_Energy_balance_validation.pdf

Appendix D – Statistical significance of tests

Purpose of tests

Laboratory measurements are the only accurate method to determine whether Heat Transfer Modifiers can improve boiler efficiency by 2% or more. The method compares the measured thermal efficiency of a boiler with and without a Heat Transfer Modifier present and operating under controlled laboratory conditions. The purpose of this Appendix is to distinguish any efficiency improvement from experimental variation.

Test numbers and resolution

The measured efficiency of any boiler in the laboratory will vary for many reasons, which include:

a) Differences between test rigs and rig operators

b) Differences between interpretation of standards

c) Position of sensors

d) Accuracy of measuring instruments

e) Ambient conditions varying from day to day and by time of day

f) Variability in time to reach steady-state readings

g) Variability in gas flow and air intake rates

h) Variability in air intake temperatures

i) Variability in inlet water temperature and flow rates

j) Variability in combustion

k) Transient heat flows and storage

By carrying out tests in the same laboratory and operated by the same operator(s), the variability in the results due to (a) to (c) will be eliminated. The accuracy required by EN483:1999+A4:2007 (page 89) is +/-2% and takes into account transient effects on efficiency by insisting that three consecutive measurements (each over 10 minutes) must be within 0.5%, or that the average of ten consecutive 10-minute periods is recorded (page 92).

Table 3 below shows the number of independent[4] measurements required to resolve any difference in efficiency owing to a Heat Transfer Modifier from that of random experimental variability. For example, three measurements of the efficiency of the system without a Modifier and three with a Modifier would be required to confirm a difference owing to a Heat Transfer Modifier of at least 1.7% with 95% confidence. That is, 1 in 20 trials would erroneously identify a difference of at least 1.7% owing to a Heat Transfer Modifier.

[4] The definition of 'independent' in this context means that one measurement does not affect another, not whether the test is undertaken by a third party.

Table 3 also assumes the variability of results is the same for the cases with and without Heat Transfer Modifiers. This is a reasonable assumption and can be checked from the results.

Number of tests per scenario	Minimum distinguishable efficiency improvement (95% confidence)	Minimum distinguishable efficiency improvement (99% confidence)
2	2.9%	7.0%
3	1.7%	3.0%
4	1.4%	2.2%
6	1.1%	1.6%
8	0.9%	1.3%

Table 3 - Sample numbers and minimum resolution[5]

Since any improvement is based on a speculative and unproven idea, a tighter constraint of 99% confidence rather than 95% confidence is required. To distinguish an improvement of at least 2%, six independent measurements per scenario are required, assuming that repeat measurements per scenario vary by ±2% for 19 out of 20 results. Note: once the results are known the actual variation of the results (rather than the above assumption) will be used to establish the minimum distinguishable improvement, which will differ slightly from Table 3. BRE may assist in the required statistical activities upon request.

The shorter the measurement period the more variable the results and, more importantly, the consecutive results are less independent. To satisfy full independence, a single test would require the warm-up period and three ten-minute measurements. To require that each separate test includes a warm-up period may be too onerous, since twelve tests would be required to achieve a minimum resolution of 2%. Therefore, since the EN483 test for equilibrium involves three 10-minute measurements (page 92, EN483:1999+A4:2007) it is taken that a 30-minute test period constitutes a separate independent measurement.

The time of day may affect the measurement (e.g. the laboratory may be colder in the morning than afternoon), it is therefore required that the whole test is repeated (measurement period and initialisation period) at least once per scenario.

Table 3 shows that six separate measurements per scenario are required to achieve a resolution of 2%. To ensure result acceptability, if the variability of the results is higher than expected, it is recommended that eight separate measurements per scenario are carried out. The required test schedule is shown in Table 1 of Appendix A.

The required analysis of the test results is outlined as follows:

a) Calculate the boiler heating efficiency of each independent test with and without the Heat Transfer Modifier present

[5] Based on a statistical test of unmatched samples with the same standard deviation using a one tailed Student T test.

b) Undertake a statistical F Test at the 5% level of significance to determine if efficiency variances with and without the Heat Transfer Modifier are the same or not. Depending on the result of the statistical test proceed to c) or d).

c) If variances are the same undertake a statistical Student T test on unmatched pairs assuming equal variances, testing whether the mean efficiency with Heat Transfer Modifier is significantly greater than the mean efficiency without the Heat Transfer Modifier by at least 0.5 percentage points, with 99% confidence.

d) If variances are not the same, undertake a statistical Student T test on unmatched pairs assuming unequal variances, testing whether the mean efficiency with Heat Transfer Modifier is greater than the mean efficiency without the Heat Transfer Modifier by at least 0.5 percentage points with 99% confidence.

e) If the result of c) or d) is affirmative (i.e. the mean efficiency with the Heat Transfer Modifier is significantly greater than the mean efficiency without the Heat Transfer Modifier by more than 0.5 percentage points) the benefit assigned to the Heat Transfer Modifier is the difference in the mean efficiencies with and without the Heat Transfer Modifier. If the result is not affirmative no credit can be given.