Review of the methodology for FGHRS in SAP

Final report

September 2021

Any enquiries regarding this publication should be sent to us at:
enquiries@beis.gov.uk

Executive summary

BEIS issued a tender to independently investigate the FGHRS methodology in SAP. The work was won by Kiwa Ltd and started in late 2019. Initial work focussed on the views of BEIS and the stakeholders, contact with BRE was via BEIS and for acquisition of data and clarifications only.

It was clear that the main issue was with the calculations used by BRE to determine the potential savings attributed to FGHRS. These and alternate proposals were reviewed in some depth and issues determined.

Issues were identified, in all methods, primary concerns were:

- Manual pre-processing of data
- Allocation of space heating throughout the day
- Calculation of duration of DHW draw-offs
- Calculation of reduction of wasted water in DHW circuit (so called 'combi losses')

All the methods were based on theoretical treatment of the thermophysical processes, but there was little data to support the results obtained. The interactions between the space heating load and DHW are complex and standards-based boiler space heating and domestic hot water tests are of limited use. Kiwa completed a range of tests using their Dynamic Heat Load Test Rig (DHLTR) that allows a boiler to be exercised in a way that it would be used in a property, with mixed and simultaneous heating and DHW loads. These tests were completed using boilers with and without FGHRS over a wide range of heating loads and DHW loads. This work allowed potential savings to be determined by combining experimental work with SAP evaluations to determine likely annual savings from various types of FGHRS.

These comparisons showed that the current SAP procedure for instantaneous FGHRS produced results close to the experimental work. However, storage FGHRS which use the mathematical procedure described above to determine savings appear to greatly overestimate the potential savings in all cases.

As a result, a new mathematical method, based on the previous versions was developed and robustly checked to ensure both mathematics and thermophysical processes were correctly represented. This model now produces results much closer to the experimental results.

However, the 'additional combi-losses' (these being losses that are attributed to operation of a combination boiler but occur externally to it, such as losses from DHW lukewarm water being discharged to waste) that have previously been included in these savings, now need to be moved into SAP itself, this is because the baseline situation of not having boiler DHW data (and hence the default additional combi-loss) is no longer true, and many base boilers have DHW test data, resulting in a different calculation path through SAP. Since it is not possible to fix which boiler may be combined with an 'add-on' at the time the FGHRS is submitted to PCDB, this needs to be addressed within the SAP procedure; this may not be possible in SAP

2012 but should be addressed in SAP 10, in which, SAP Table 3a will need to be amended to include a default saving for FGHRS enabled boilers.

As an interim measure, for SAP2012, it is suggested that FGHRS appliances that are compatible with a range of boilers, need to have 2 entries. One entry for when combined with a boiler with no DHW test data and one entry for those boilers that have DHW test data.

It is suggested that a similar physical testing regime is maintained, with some modifications. In particular, tighter test specification (ambient temperature and flow conditions) and boiler disabled on discharge testing, so the retained heat in the store can be measured more accurately. This will maintain compatibility with previous entries to PCDB as far as possible.

The main recommendations from this work are that:

1. The new mathematical methodology for assessing FGHRS with stores be adopted.
2. The new test regime be implemented for all new FGHRS entries to PCDB
3. All existing entries to be recalculated or where this not possible a default value be given instead.

Contents

1. Introduction

1.1 Reasons for research

The Standard Assessment Procedure is the UK Government's method for calculating the energy performance of domestic buildings and is used by architects, building engineers, surveyors, and anyone generally involved in the housing industry.

SAP modelling takes many different characteristics as inputs, relating to the property's construction, its location and its occupancy, and outputs information on the performance of the building, in terms of its annual energy requirement.

Critical inputs to the model which have a significant impact on the performance of a building are its heating system design, fuel type and operating regime. Full details of this must be inputted to the SAP model to get an accurate prediction of its energy requirement.

The SAP model allows the user to specify, in addition to the main components of the system (e.g. heating system technology, fuel type and emitter type), any energy saving add-ons or ancillary components that have been installed with the assumption that their inclusion will reduce overall energy consumption and hence give a boost to the building's performance. Examples of these add-ons are smart boiler controls (with automation and/or optimisation features), and weather/load-compensating thermostats. The way the model attributes energy savings varies with technology.

One such add-on is the Flue Gas Heat Recovery System, with several manufacturers now offering these devices as stand-alone units or as components to be integrated into the main heating technology (usually condensing gas combi boilers).

There is a methodology within the SAP model to attribute the savings achieved by these types of units, but as much of the methodology has been developed over several versions of SAP, this sometimes means similar types of FGHRS are treated differently, depending on when they were submitted for inclusion in PCDB/SAP. Additionally, some manufacturers have posed questions about the accuracy of the methodology.

This research project aimed to determine how FGHRS units perform within a domestic space heating and domestic hot water scenario, to determine how accurate the SAP models for boilers systems with FGHRS are, using the current method for converting FGHRS empirical data, and whether any alternative methods could improve the accuracy of this modelling.

Finally, a new methodology has been developed to convert test data into inputs for the SAP calculation.

1.2 Project objectives

The objectives of the study were to:

1. Engage with the stakeholders in the FGHRS industry
    - Obtaining an overall picture of the FGHRS market
    - How they feel SAP works for this technology
    - Understanding industry’s concerns on FGHRS in SAP
2. Review the current state of the technology, and its modelling in SAP
    - To understand the types of FGHRS units available
    - To understand how well the current methods reflect the performance of the available technologies
    - To understand where the methods underperform
3. Fill any knowledge gaps by carrying out tests
4. Recommend improvements or redesign of the existing test requirements and/or calculation methodology

1.3 Summary of work carried out

The four objectives listed above were addressed in the following manner:

1. Engage with stakeholders in the FGHRS industry

The team at Kiwa met with different stakeholders, to understand their concerns about the current methodology, and how they see the issues being resolved. A number of documents relating to various methods for FGHRS performance modelling were received and equipment for testing was supplied.

2. Review the current state of the technology, and its modelling in SAP

The received documentation was reviewed, and all modelling and technology status updates noted. Section 2 details the state of the technology and the legislative landscape in which it fits, whilst section 3 gives a concise review of the available methods for modelling FGHRS performance.

3. Fill any knowledge gaps by carrying out tests

Two FGHRS units were received from stakeholders: one external unit with a store and one integrated instantaneous unit. A compatible boiler was received with the external unit, and a boiler of the same model without a FGHRS was received with the integrated instantaneous unit. All four of the boiler/FGHRS systems were tested on Kiwa’s Dynamic Heat Load Test rig (DHLTR) to determine their performance in a domestic heating setting.

This was done for a wide range of house sizes and corresponding hot water loads. Details of the testing performed, can be found in section 5.

4. Recommend improvements or redesign of the existing test requirements and/or calculation methodology

The findings from the testing were compared to SAP runs for each of the current models. The findings suggested that a change in modelling approach may be necessary; suggestions for this model, and evidence for its effectiveness, are presented in section 6.

2 Background

2.1 Principles of Design & Operation

Flue gas heat recovery units are devices that can be used with combi boilers to improve the efficiency of domestic hot water (DHW) production. They are designed such that incoming mains water is preheated before entering the boiler by exposing it (via a heat exchanger) to the exiting flue gases and extracting the otherwise wasted heat. The amount of available energy for recovery is limited by the flue gas temperature (FGT), the water vapour content and state, and this in turn is determined by the type of boiler and central heating temperature.

The effect of pre-heating the incoming mains water means that less heat is required to be input from the boiler to raise the temperature of the DHW to that required for delivery. This can lead to savings in terms of gas used by the boiler and, as water at the right temperature can be delivered more quickly, there can be additional savings from reducing the amount of lukewarm water that is rejected by the user before it is hot enough.

If the FGHRS contains a volume of water (or condensate), it is known as a Storage Flue Gas Heat Recovery System (SFGHRS). In such devices the store of water is heated by the flue gases via the heat exchanger. This volume of water may be contained in the same unit around the flue, or in a cylinder next to the primary FGHRS unit. The store may be insulated, depending on the store location and the manufacturer’s design.

SFGHRS can transfer heat either when the boiler is operating in hot water mode or when the boiler is operating in space heating mode. When the boiler is operating in hot water mode the transfer of heat takes place directly from the flue gas to the incoming water. When the boiler is operating in space heating mode the energy must be stored and transferred at a later time, when the boiler switches over to DHW mode. This can either be achieved by residual heat in the body of the FGHRS, or more often via the stored water (acting as a thermal store) within the SFGHRS.

The savings that are achieved through the transfer of heat directly to the incoming cold water are known as direct savings and the savings that can be transferred from the flue gas, via an internal store and then to the incoming cold water are known as deferred (or indirect) savings. SFGHRS can provide both direct energy savings and deferred savings whilst Instantaneous FGHRS (IFGHRS) provides predominantly direct savings (although there are still some indirect savings from the water and metal work comprising the IFGHRS).

The heat exchanger is usually made of a corrosion resistant metal. This facilitates heat transfer between the flue gases and the incoming/stored water, whilst providing a long lifetime by avoiding corrosion, given that the heat exchanger will be perpetually in contact with both water and condensate.

With condensing boilers, the FGT is typically around 50 to 70°C. Dependent upon the temperature, pressure and other physical properties, the flue gas maybe above or below the dew point, which will substantially alter the amount of energy available for the FGHRS to utilise (as this will determine whether the energy contained in the water vapour can be recovered). There is a complex dynamic interaction between the operation of the boiler for central heating purposes and the production of DHW via a FGHRS. Understanding of the nature of these interactions is essential to developing an accurate model for treating these devices in SAP and has formed the basis for the test programme.

The savings that can be achieved depend on factors that relate to the thermophysical properties of the FGHRS and boiler, and factors that relate to the operation of the system (length, frequency of draw offs, in combination with heating patterns). The most accurate methodology for modelling these savings would have to include information on all these areas.

2.2 Categorisation

FGHRS can currently be defined by 3 main features:

1. Immediacy – when the heat is used:
   - those which provide heat for immediate (instant) use
   - those that store heat (usually in a water store) for later (deferred) use
2. Energy requirement:
   - Passive systems - require no additional energy input
   - Active systems - require additional (normally electric) energy, to operate, for example the pumping of hot water into an externally located hot water cylinder
3. Structure:

- As a part of a boiler system (integrated)
- As an add-on unit to an existing boiler

If the store of water is separate to the primary unit then a pump or other means of circulating water from the heat exchanger is required. Pumps etc will draw electrical power. FGHRS that do not consume additional power are called passive FGHRS (PFGHRS); these units make up most of available models on the market.

As of the 26/05/2020, the following numbers of products were listed on the PCDB for use with mains gas (some products can also be used with LPG, in which case there is a duplicate entry but the listed performance may be different):

- 25 entries listed as FGHRS, of which 7 are integrated to the boiler
- 34 Boilers on the PCDB with integrated FGHRS

2.3 Legislative landscape

The characteristics of gas boilers supplied in the UK are regulated. Determination of performance characteristics depends on application of testing defined in relevant standards. Data from testing forms part of the process of assessing the performance of buildings where gas boilers are installed. Here the information relevant to FGHRS is summarised.

2.3.1 Gas Boiler Legislation

Domestic Gas Boilers in the UK are covered by several pieces of legislation, primarily originating as European directives. These legislative acts that apply are listed below. In each case listed, a FGHRS is considered a component part of the boiler system, and therefore must be approved with a specified boiler. This means it is not currently possible to sell a general purpose FGHRS unit; each FGHRS unit must be installed onto a boiler with which it has received overall boiler system approval.

- Gas Appliance Regulation (GAR) 2016/426 [1]
- Boiler Efficiency Directive (BED) 92/42/EEC [2]
- Energy Related Products (ErP) Directive 2009/125/EC [3]
- Energy Labelling Directive 2010/30/EU [4]
- Low Voltage Directive (LVD) 2014/35/EU [5]
- Electromagnetic Compatibility Directive 2014/30/EU [6]

The 2018 update to the Building Regulation Document L1B (colloquially named the ‘Boiler Plus’ regulation) [7], introduced in the UK in April 2018, set out new requirements to improve the efficiency of all new domestic boilers. One of the requirements of this regulation was to install at least one of four energy saving technologies alongside a new gas boiler; one of these options was a FGHRS unit.

2.3.2 British Standard BS EN 13203-2:2018 [8]

(Gas-fired domestic appliances producing hot water Part 2: Assessment of energy consumption)

This standard is used to measure the energy consumption of domestic gas appliances when producing hot water. Appliances with FGHRS can be tested to this standard and any improvement in efficiency due to the presence of the FGHRS will be reflected in the test result. The savings due to the device could be derived from a test with and without the device.

The standard tests DHW performance of the boiler in isolation and does not reflect the interaction between space heating and DHW production, so only the instantaneous savings of FGHRS can be realised and thus this standard does not provide method for assessing the performance of SFGHRS.

2.3.3 Draft standard prEN13203 -7

(**Gas-fired domestic appliances producing hot water** – Part 7: Assessment of energy consumption of combination boilers equipped with a passive flue heat recovery device) [9]

This draft standard is currently being developed by the European Committee for Standardisation (CEN). The final version is due to be published at the end of Q1 2021. The version of this standard reviewed for this project was dated 04/11/2019.

EN13203-7 is designed to be an extension to the domestic hot water testing in EN13203, particularly to part 2 (discussed above). It seeks to determine the energy consumption of a boiler unit fitted with a FGHRS, including specifying three extra tests (one to ensure conformity with 13203-2, and two more for energy recovery determination), and a method to determine the contributions of the FGHRS. A more detailed explanation of the methodology in this standard is contained in section 4.2.3.

2.3.4 British Standard BS EN 15502

Gas-fired heating boilers

15502-1 Part 1: General requirements [10]

15502-2-1Gas-fired heating boilers Part 2-1: Specific standard for type C appliances and type B2, B3 and B5 appliances of a nominal heat input not exceeding 1000 kW [11]

15502-2-2: Specific standard for type B1 appliances [12]

BS EN 15502 contains a number of tests that ensure the safe and effective operation of gas boilers, including domestic combination boilers with which FGHRS units will be supplied. The standard specifies in its introduction that the legislation identified above does not consider FGHRS separate to the boiler system currently. EN 15502 specifies test methods for the boiler types specified in BS EN 1749 [13], which defines boiler types based on the air intake and combustion product exhaust systems. As FGHRS fundamentally alter these gas flow systems, they must be tested as part of the flue system for a given boiler, to qualify that the boiler meets performance standards with the altered flue in place. FGHRS systems cannot be signed off as a safe addition to the installation without verification to this standard as part of a boiler system.

2.3.5 Standard Assessment Procedure (SAP)

The SAP is the UK Government's method for calculating the energy performance of domestic dwellings. It has been a legal requirement (under part L of the Building Regulations) since 1995 that every new building must undergo a SAP assessment, and therefore SAP holds great significance to building constructors. As inclusion of a FGHRS system in a SAP calculation is likely to lead to an improvement in the energy rating of the property, SAP acts as an incentive for developers to include FGHRS in their housing design. It is therefore very important that the performance modelling of FGHRS units in SAP are accurate, to give the fairest indication possible of the unit's performance in the home.

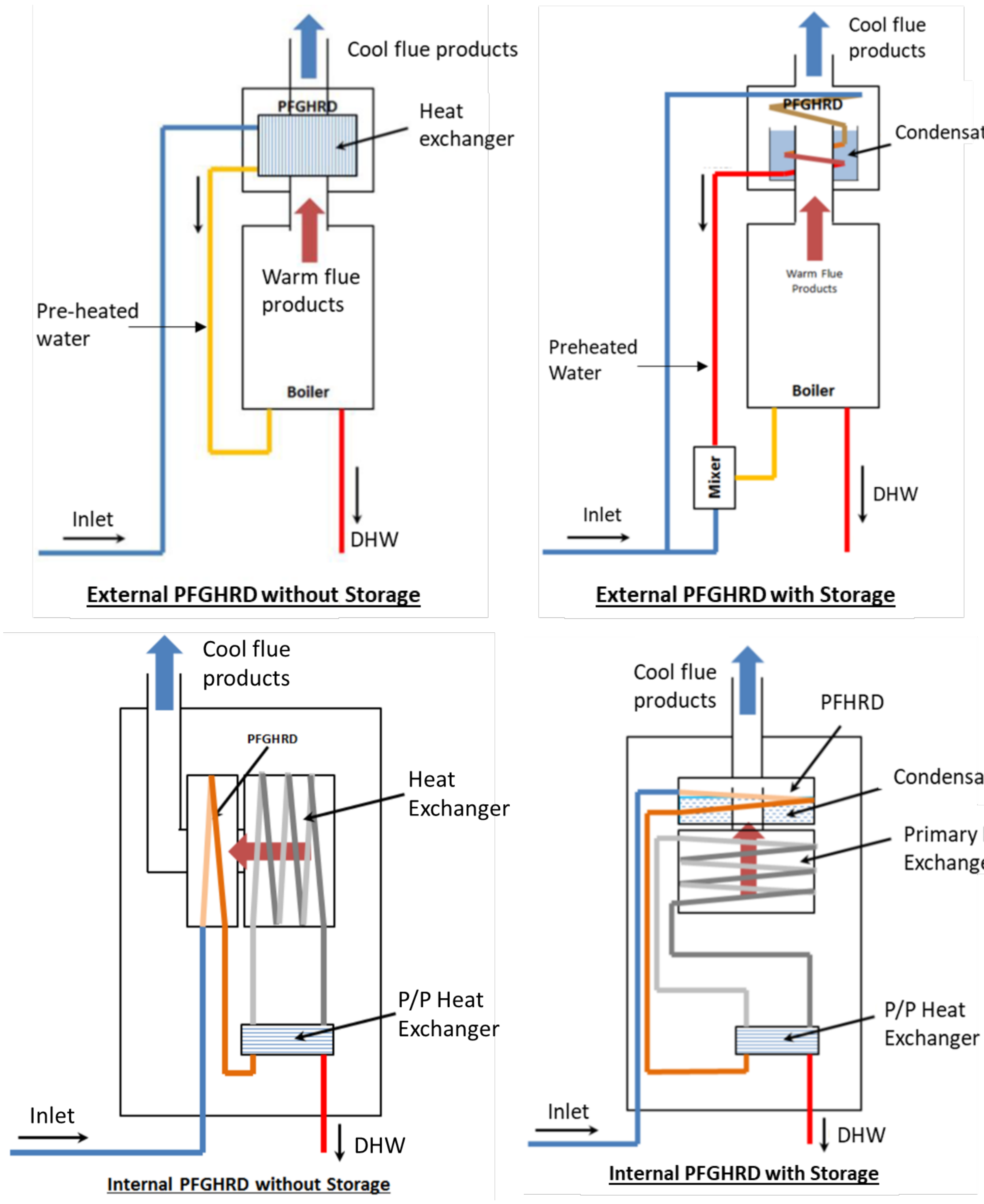
This review mainly looks at the methodology for handling FGHRS in SAP (specifically SAP 2012 [14], the current version at time of writing) and a wider explanation is contained in section 4.1.

The SAP is supported by the Products Characteristics Database (PCDB) [15], which holds information on product performance that can be used as input to the SAP model. Amongst the technologies included on the PCDB are condensing gas boilers (which can be listed alone or with integrated FGHRS) and Flue Gas Heat Recovery Systems (as a separate section). The boiler section of the PCDB was formally known as the Seasonal Efficiency of Domestic Boilers in the UK (SEDBUK) database.

2.4 Current innovation in FGHRS technology

FGHRS technology is still relatively young, and a number of different designs of FGHRS currently exist. The market has far from settled on an optimum design, and therefore there are multiple areas for innovation within FGHRS design. Whilst the details of such developments are proprietary information for the FGHRS manufacturers, some of the general trends are discussed below.

The primary focus area for FGHRS technology currently is around the location of the FGHRS unit, and how it contacts flue gas and cold water to achieve the desired water pre-heating. As discussed above, FGHRS units can be sold either internally within a boiler, or as an external add-on product. They can also contain a store for providing indirect heat to the cold water, or just a heat exchanger for direct heating only. Of particular importance is how the DHW from the store is handled, whether it passes through a temperature controlling mixing valve or not, can impact the savings obtainable from the FGHRS. Such mixing valves are often necessary to restrict the DHW inlet temperature into the boiler, to ensure safe and stable operation. The variety of configurations allows for a wide scope of designs; a number of the potential configurations are shown in Figure 1 below.


External PFGHRD without Storage

External PFGHRD with Storage

Internal PFGHRD without Storage

Internal PFGHRD with Storage

Figure 1: Outlines of potential configurations for FGHRS installation (Adapted from Enertek International, via BEIS [16])

An alternative set up is to use a store of preheated water external to the heat exchanger (i.e. mounted outside of the flue line), that could be a significantly larger volume compared with in-line units. A typical configuration is shown in Figure 2 below. This larger store could provide larger amounts of indirect heating, although separate systems for keeping the store warm, and a means of transporting warm water between the store and the heat exchanger would be required.

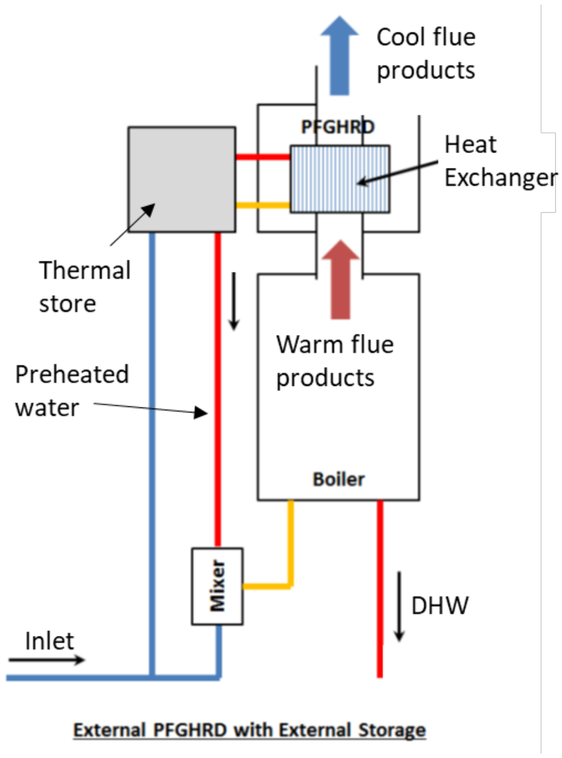


Figure 2: Configuration of an external FGHRS with a separate external store (Adapted from Enertek International, via BEIS [16])

In addition to the location of the FGHRS, and whether it contains a store or not, the other main differentiator between FGHRS units is whether there is another source of energy into the unit. Whilst the main focus up to now has been on passive flue gas heat recovery design (i.e. those that do not have extra energy inputs), alternative designs with electrical inputs (so called active FGHRS units) are also being innovated. Active designs could simply include an electric pump to circulate water between, for example, a FGHRS with a heat exchanger only and an external store; or can be more broad in scope, for example using energy inputs from solar energy systems, either as electricity from solar PV, or hot water from solar thermal systems.

There is also some current innovation around heat exchanger materials. The heat exchanger within the FGHRS must be made of a corrosion-resistant, thermally conductive material, in order to facilitate heat transfer between the exiting flue gas and the incoming cold water. Recent developments in this area have included moving towards a lower thermal mass material, which aids the efficiency of direct heat recovery, although reduces the ability of the exchanger to retain heat as a store.

3 Stakeholder engagement

3.1 Identification of stakeholders

A list of potential stakeholders was compiled from organisations known by Kiwa and BEIS to be interested in the review, as well as identifying manufacturers with FGHRS entries on the PCDB. The Heating and Hot water Industry Council (HHIC) was approached to circulate notification of the project to all its members, and specifically to the organisations identified from the PCDB search.

A selection of organisations responded, wishing to be included in the review:

- Groupe Atlantic (representing Ideal Boilers)
- BDR Thermea (representing Baxi Boilers)
- Vaillant
- Cosmogas
- Canetis

The Building Research Establishment (BRE) was also identified as a stakeholder.

3.2 Stakeholder interaction

Stakeholders were contacted to inform them that Kiwa had been commissioned to undertake the FGHRS review together with an explanation of the methodology that would be used. They were also asked if they would like to provide test data and/or test equipment to support the project.

In response, two organisations requested face to face meetings with Kiwa: Groupe Atlantic and Canetis. During these meetings both organisations offered test data to support the project, as well as offering to supply equipment for testing. Non-disclosure agreements were signed with both parties.

The timeline and results of stakeholder interaction are recorded in Appendix D.

4 Review of current SAP FGHRS methodology

4.1 Overview of the current methodology

To date, the methodology for calculating the savings attributable to the use of FGHRS has been developed by the BRE who also developed the wider SAP methodology. For the purposes of this report this method shall be referred to as the current (or BRE) method.

The current method is described in the document "Flue Gas Heat Recovery systems (FGHRS): Data requirements and assessment methodology for recognition in SAP (SAP 2009 revision)", written by John Hayton for DEFRA in 2010 [17]. The document describes the empirical tests that are required to determine the performance of the FGHRS as well as a description of how the results of these tests together with the thermophysical properties of the device form the inputs into a model to calculate a series of coefficients for use in SAP.

4.1.1 Test requirements

The testing required by the BRE depends on whether the FGHRS is an instantaneous unit, or whether it contains a store. If instantaneous, then the only required tests are a hot water No 2. tapping test (as laid out in EN 13203:2), both with and without the FGHRS operating. If a thermal store is present in the unit, then the tapping tests are still required, as are three new, separate tests:

- Charging - The store is heated by primary space heating water flow (at 48-50°C and 30% nominal space heating output or minimum boiler turndown, whichever is lower) from ambient until the store temperature reaches equilibrium.
- Cooling - The system at 50°C is switched off and the temperature of the FGHRS store allowed to passively cool to within 0.5°C of the ambient temperature.
- Discharging – The system at 50°C has hot water drawn off at a specified rate (6 l/min) until the system has cooled to within 0.5°C of ambient

The data from these tests is then used to estimate an annual energy saving attributed to the FGHRS, assuming a daily hot water tapping pattern which is repeated over the course of a month. For instantaneous devices, up to SAP2009, this calculation was simple, as the noted total efficiency of the boiler with and without the FGHRS were used to calculate a factor Kf (fractional savings), which is added to the FGHRS record in the PCDB database. For new entries to the PCDB since SAP 2012, instantaneous FGHRS boilers are added directly to PCDB using the EN13203-2 test data.

For units with storage, the data from the other three tests, particularly the rate of change of temperature functions, are additionally used to calculate the energy saved over the course of a year, assuming a space heating demand for the year in addition to the hot water tapping.

4.1.2 Pre-processing of test data

The BRE method uses the following equation as the basis for its annual deferred energy saving calculation:

$$\frac{Q_{store,t+\Delta t} - Q_{store,t}}{\Delta t} = \dot{Q}_{k,t}(T_{store}, T_{amb}) + \dot{Q}_{h,t}(T_{store}, T_{amb}) + \dot{Q}_{c,t}(T_{store})$$

- [1]

Where Q is energy (kJ), $\dot{Q}$ is energy flow (kW), *t* is time (s), *T* is temperature (°C), *Δt* is the change in time, and the subscripts *amb*, *c*, *h*, *k*, *store* and *t* represent ambient, charging, discharging, cooling, store and time respectively. The notable point about the BRE implementation is the use of discrete differentiation in order to calculate the gradient in each of the three experimental results – the gradient is calculated by determining the gradient between each point and the last, using a simple gradient formula:

$$\dot{Q} = \frac{Q_i - Q_{i-1}}{t_i - t_{i-1}}$$

- [2]

Where *i* is the current data point, and *i – 1* is the previous data point.

In addition to these gradients from the tests, the BRE implementation also dictates the use of scaling factors to alter the gradients from those found under test conditions to those expected in the household setting for which the SAP is being calculated. These respective factors are:

Charging – a linear scale factor based on the space heating demand, the no. of hours and days of heating demand and the power output of the boiler during the charging test

$$\frac{Q_{sh}}{N_h N_d P}$$

- [3]

- Cooling – a non-linear scale factor based on the modelled room temperature and the room temperature during the empirical cooling tests (subscript *r* is the average UK domestic room temperature, typically set to 20°C)

$$\left(\frac{(T_{store,t} - T_r)}{(T_{store,t} - T_{amb,t})}\right)^{1.25}$$

- [4]

- Discharging – the ratio of the volume flow rate in the daily profile, V_i to the volume flow rate used in the empirical test, V_o

$$\frac{V_i}{V_o} \qquad [5]$$

The ultimate energy saving for the year is then calculated by finding the rate of change of temperature for every time point within the modelled day and summing them, then multiplying by the thermal capacity of the system and the number of days in the heating season to get the overall deferred heat saving.

The coefficient values that are entered into the PCDB database are calculated in a spreadsheet written by the BRE, which takes in the datasets from the empirical tests and implements the mathematical method. The methods implemented within this spreadsheet require the input data to be continuously trending either up or down (depending on the test being analysed), and therefore some pre-processing (e.g. changing of the gradient timestep) of the data is required in order to get the sheet to run smoothly. The method that BRE uses to perform this processing was published in February 2009, and it has been shown that the data is manually smoothed out (by removing data points) in order to ensure spreadsheet stability.

As there are many permutations of space heating and hot water demand, and the SAP requires a relatively simple input (to keep the entire calculation manageable), the savings are determined as follows:

- Six space heating requirements are selected for calculation. These are typically 0, 200, 1000, 2000, 4000 and 20000 kWh/month, although other values may be used.
- The total energy savings (direct and indirect) are calculated for a range of hot water requirements (61 – 236 L/month) for each space heating demand in turn.
- The six, energy savings vs hot water demand curves are then independently fitted to a logarithmic function, tuning three regression coefficients.
- The calculations are repeated both without and with a ‘keep-hot’ facility being present

This provides 2 lots of six sets of three coefficients which are then stored in the PCDB for SAP calculation

4.1.3 Summary of information required

The SAP 2009 document [17] outlines several pieces of input information required as input to the BRE method:

FGHRS Technical Specification

- Specific thermal capacity of the heat exchanger materials (kJ/kg/K)

- Weight of heat exchanger(kg)
- Store volume (litres)

The specific heat capacity of water is also required, but this is provided by BRE.

The SAP 2009 document gives the following as further required inputs for systems with external stores:

- Total length and diameter and insulation conductivity and thickness of connecting pipework between store and heat exchanger
- Total length and diameter and insulation conductivity and thickness of connecting pipework between store and cold water feed to boiler
- Minimum height between the store’s highest domestic water level and the highest water level in the heat exchanger

Boiler properties

The SAP 2009 method specifies that all testing of the FGHRS must be done with a new combi boiler without a keep hot facility. In addition, the following information is required:

- Boiler name and model
- Minimum firing input rate in central heating mode (kW net)
- Efficiency (as declared under the BED [2] at full and 30% part load
- Seasonal efficiency (SEDBUK) – this must be a minimum of 90% for condensing boilers.

Test data

The results of all four of the tests discussed in section 4.1.1 are required as inputs into the model. The EN 13203-2 test serves to determine performance when the boiler is running in summer mode (i.e. is only providing hot water, and not central heating). The full results of the charging, discharging and cooling tests specified by the SAP 2009 method are present in full in the spreadsheet, and are used to calculate the changing temperature of the store in the SFGHRS. The charging, discharging and cooling tests are not required for FGHRS systems without a store.

4.1.4 Discussion of the BRE method

The current method provides a means for calculating both the instantaneous and deferred savings from FGHRS. This means that both instantaneous devices as well as SFGHRS can be handled in SAP. Additionally, any non-passive FGHRS can be handled as there is the provision to input external power consumption which is subsequently used in the SAP method.

There are two routes for listing FGHR units on the PCDB, depending on whether the FGHRS has a store or not:

Direct Heating (No store)

The results of the two EN13203-2 tapping tests (both with and without the FGHRS) are passed directly to PCDB for evaluation and upload.

Direct & Indirect Heating (Store present)

The results of the four tests (EN13203-2 tappings, charging, discharging & cooling), and the data outlined in section 4.1.3 are passed to BRE, who use their model following the theory outlined above to generate 2 lots of six sets of coefficients for FGHRS modelling. These are then directly entered into the PCDB.

A number of specific issues were identified with the BRE methodology during the review. Firstly, the allocation of space heating throughout the day made little practical sense, particularly at very low or very high space heating demands. The current methods assume a bimodal space heating profile, spread over 11 hours. Under conditions close to that measured in the empirical test, this proves reasonable. However, at low space heating demands, such as 200 kWh/month, the average heat output of the boiler across this 11 h day is 0.6 kW, which is 2.5% of the rated power of the boiler, this is not possible without considerable cycling which undermines the logic of the BRE method. In this scenario, there would be almost no recoverable heat from the flue, and therefore the current method overestimates the possible savings in this heat range.

Likewise, when the space heating requirement is high (e.g. 20000 kWh/month), the averaged heat output across the available heating time (60 kW) is greater than the maximum output of the boiler (typically 25 kW for a combi appliance). Again, this means that the estimated savings in the model will be greatly overestimated, as in this case the total heat delivered by the boiler is unrealistically high. As can be seen, the overestimations caused by these scaling factors can be significant at the extremes of heat demand.

Secondly, the calculation of the hot water-draw off does not reflect use in practice. In the BRE methodology, the volume of water calculated to be drawn off during periods of hot water demand is based on the lowest acceptable temperature dictated by the EN13203-2 tapping cycle (i.e. 25°C). In reality, the delivered hot water would pass through the boiler and be heated to the set point temperature (which during testing is over 55°C to ensure test conditions for the most demanding draw-offs are met). This would also be the case when installed in a property, the DHW exit temperature is generally set to satisfy the most onerous demand, and not changed for every draw-off, but mixed at the tap to the correct temperature. This is significant as the amount of hot water delivered during each step of the tapping cycle is based on the total energy delivered; having a low temperature hot water stream results in a large amount of water passing through the FGHRS and the boiler, which allows much greater opportunity for the store to preheat the water. This results in an overestimation of the indirect savings.

In addition, the ‘wasted water’ savings appear to be handled incorrectly by the current method (especially by SAP’s handling of these systems). The current model calculates a saving for systems without a keep-hot facility of based on the ‘additional combi-loss’ default value of 600 kWh/year (from SAP Table 3a). This is based on the default situation where the boiler has not been tested to EN13203-2 or OPS-26. The calculated additional saving is approximately 75% of this value or 450 kWh/year. This may well be true if the FGHRS is being matched with a boiler that has not been tested (to EN13203-2). However, if the FGHRS is being matched with boiler that has full test results, then the combi-losses are determined by reference to SAP tables 3b or 3b. These tend to give much lower additional losses for combis. For the boilers tested in this work the SAP-calculated ‘additional combi-loss’ was around 11 kWh/month equivalent to about 132 kWh/year. It can clearly be seen that if the FGHRS methodology is predicting a saving of 450 kWh/year and yet the combi-loss is only 132 kWh/year, the methodology is predicting a greater saving than is actually available to save and therefore the savings are significantly overestimated (to the extent of effectively creating energy). This is discussed further in Error! Reference source not found.. It is appreciated that the additional combi-loss calculated from DHW test data can vary greatly, this is discussed later. However, the point is that one assumed value of 600kWh/year (50kWh/month) in the model is not true for most boilers/FGHRS with DHW test data.

The scaling function used within the BRE method is a linear function, as shown in equation [3] above. The use of this function is problematic as the space heating load considered moves further from the test conditions.

At high space heating loads, the linear scale factor quickly reaches levels of boiler output that the boiler itself cannot match. This is because the empirical tests are typically performed at 30% boiler output, which is set to be a scaling factor of 1. This sets the maximum boiler output at a scaling factor of 3.33. Other controls implemented in the spreadsheet, such as the use of maximum and minimum store temperature values serve to reduce this large over-performance in high space heating scenarios, but these are arbitrary mathematical caps that may induce distortion in the calculation in other ways.

One of the mechanisms that does this is a cap on the maximum rate of temperature drop during discharge. This is calculated within the spreadsheet by inverting the thermal mass of the FGHRS. By doing this, the rate of temperature drop within the store is steadied (so mimicking the greater energy content of a higher thermal mass store), but at the cost of arbitrarily limiting the effective heat transfer rate from the store into the outgoing hot water flow.

At low space heating loads, rather than turn down to ever lower power outputs, the boiler will modulate down to say, for example, 30%, but beyond that it will start to turn on and off. Whilst the modulation will result in a linear amount of energy available from the boiler, the current calculation for available energy in the FGHRS store is overestimated, on/off operation will result in the boiler firing for short bursts, and therefore regularly failing to meet the expected 50°C of the store.

It is discussed above that the BRE implementation of this methodology is believed to use manual pre-processing to improve model stability. This manual pre-processing may have a significant effect on the output of the model on multiple fronts. Most significantly, it cannot be applied repeatably and fairly, because it is done manually. As such, this approach introduces uncontrolled uncertainty to the process. Given that the BRE method serves as a standard method to convert the performance of a FGHRS unit into an input for SAP, it is imperative that uncertainty is avoided wherever possible.

In addition, this manual pre-processing would disproportionately affect early in the discharge run, where the temperature in some cases holds fairly steady for a short while, before then decreasing. Because the manual pre-processing performed on a case-by-case basis, it is unknown how the effective measurement start time is (although examining the BRE spreadsheet suggests that the very start temperature from the run is considered), nor how the gradient of the discharge curve is affected, as the removal of data points that don’t continuously decrease will result in inconsistent changes in curve smoothing.

The empirical tests outlined by the SAP 2009 require an average flow and return temperature of between 48 and 50°C. All subsequent calculations of the FGHRS store temperature use 50°C as the upper limit of temperature. This may not be true for real systems, as the flow and return temperature may be set differently, depending on the requirements of the domestic system and the preference of the end user. This potential variation in temperature has not been accounted for, either in the SAP 2009 document, nor the spreadsheet implementation.

Some further assumptions are made in the methodology:

- The total indirect savings achieved by the thermal store are based on the total temperature drop during discharge periods across the modelled 24 h. This overlooks the fact that during discharge, the FGHRS store will be being charged by the hot flue gases, as well as the store being cooled by new cold water passing through the store. This therefore underestimates the total amount of energy imparted by the FGHRS store to the delivered hot water.
- The flow and return temperatures of the boiler are always 50°C.

It is notable that the configuration of the boiler and FGHRS is not considered in the current method. The means by which the pre-warmed hot water is blended with fresh cold water is an important consideration in the performance of these systems, but little consideration is given to this issue in the current methodology. This is important, as the maximum temperature that the boiler can receive water for DHW heating, and the action a mixing valve takes to meet this temperature, can greatly affect how much indirect heat saving a FGHRS can bestow. If a boiler has a maximum water inlet temperature of 30°C, but the FGHRS can heat to 50°C, then not all of the preheated water can be passed into the boiler; it must be blended with cold water to meet the boiler inlet requirements. Consequently, less preheated water is fed into the boiler, and therefore the savings imparted by the FGHRS are less. This variability is not currently accounted for in the current method.

No evidence was seen to suggest how the BRE method handles multiple FGHRS thermal stores, nor does the SAP 2009 document show how to handle these cases.

Advantages of current method:

- Existing method compatible with data in PCDB.

Disadvantages of current method:

- methodology relies on significant complex spreadsheet modelling
- large amount of manual pre-processing of test data required
- pre-processing varies on a case by case basis
- artificial limits must be imposed to ensure the model does not become unstable
- significant reliance on modelling further detaches the PCDB from real, dynamic behaviour of the unit
- testing is time consuming
- tests are non-standard

Stakeholders identified that they found the current methodology opaque, inconsistent, overly complex and commented that it relies too much on modelling rather that real test data. Certain stakeholders suggested that the case by case pre-processing of test data has led to an under representation of their device's performance and they felt that some of the linear scaling and artificial limits imposed further underestimated the performance of their device under certain conditions.

4.2 Alternative methods

The stakeholder review identified two alternative methods for calculating the savings attributable to FGHRS. These shall be referred to as Methods 1 and 2. Additionally, the draft standard prEN13202-7 contains a method for calculating the savings of FGHRS and this is referred to as Method 3.

4.2.1 Method 1 – the closed-form analytical solution

4.2.1.1 Summary

This method is based around an exponential decay function, which is derived from Newton's Law of Cooling. The derivation is an analytical one, starting with the same annual deferred energy equation:

$$K\frac{dT_{store}}{dt} = \dot{Q}_k + \dot{Q}_h + \dot{Q}_c \qquad \textbf{\textit{[6]}}$$

And from this, deriving new expressions for temperature during:

- Charging – where *h* is the heat transfer coefficient in the device, *K* is the thermal capacity, and T_{init} and T_{flue} are initial and flue (temperatures) respectively

$$T_{store,t} = \left(T_{init} - T_{flue}\right)e^{\frac{h_c t}{K}} + T_{flue} \qquad \textbf{\textit{[7]}}$$

- Cooling –

$$T_{store,t} = (T_{init} - T_{amb})e^{\frac{h_k t}{K}} + T_a \qquad \textbf{\textit{[8]}}$$

- Discharging – where the subscript *ci* is the cold inlet temperature of the water

$$T_{s,t} = (T_{init} - T_{ci})e^{\frac{h_f t}{K}} + T_{ci} \qquad \textbf{\textit{[9]}}$$

If the results of the three tests are regressed against the corresponding empirical curves, the heat transfer coefficient and the thermal capacity can be determined, and the results then expressed as a continuous function. This equation can be easily differentiated to provide the rate of temperature change values that the rest of the BRE implementation requires.

The summer mode implementation of this method is the same as the current method; the only difference lies in the calculation of the indirect heat contribution of the FGHRS store.

In addition, this method proposes that for the discharging test, a delay be placed in the calculation of the gradient, as there is a short time during the tests in which the store temperature does not decrease, whilst the pre-warmed inventory within the FGHRS drains out. It is only when fresh cold primary water is brought into the unit that the decrease in temperature begins, and it is argued that because of this delay, the current BRE implementation underestimates the temperature gradient, leading to a lower transfer of heat from the SFGHRS with consequently lower savings. This is claimed to have the effect of negating the benefit of having a high thermal store unit in the calculation. However, the fact that the outlet temperature is maintained during initial discharge also indicates that the assumption that the store is well mixed and can be represented by a single temperature is incorrect. Constant temperature discharge points to a situation where the store is not well mixed and there may be plug-flow through the store.

The closed form analytical solution, as currently implemented, uses the same experimental results as the BRE methodology, and produces results for SAP by the same means. This therefore ultimately limits its ability to correct many of the major issues with the BRE method. The exponential charging temperature curve does provide a natural upper limit to the amount of indirect heat provided at large space loads, so addressing this problem. However, it exacerbates the issue in the low space heating range, as the savings predicted by this model are larger for low demand properties than the BRE model, which already overpredicts on the basis of actual boiler run time. This method also does not address the hot water run time and waste water saving miscalculations present in the BRE method.

Advantages

- Mathematical equations are used to fit lines to the heating, cooling and discharge test results which removes the need for manual pre-processing to calculate gradients
- Does not increase the burden of testing

Disadvantages

- Does not reflect the complex interaction between space heating and hot water production
- Still requires complex spreadsheet models to be created
- Replacing linear load scaling function with a function that tends to some value may solve problem at high space heating loads but could potentially lead to unrealistic results and low or high space heating
- Little empirical backing for theory of scale up

4.2.2 Method 2 – the exponential mathematical (interim) method

4.2.2.1 Summary

This method was proposed by the same stakeholder as the closed form mathematical method, and was done as a short-term workaround to be able to use the same spreadsheet structure as is currently used, but with some modifications based on the theory of the closed-form method. This method was only ever proposed as temporary, whilst work towards a more complete solution based on the closed-form method was developed.

The only changes to the BRE spreadsheet are to the scaling of heat demand with property size, and the charging and discharging factors:

- The changes in store temperature due to both charging and discharging are determined by an equation of the form

$$T = \alpha - \beta e^{-\gamma t} \qquad \textbf{\textit{[10]}}$$

where the coefficients α, β and γ are determined by regression to the respective empirical test curves. These are implemented in the spreadsheet as a change in temperature between time steps by differentiating the temperature curve above and multiplying by the time step; this results in a linear equation with temperature.

- The heat demand is changed from a linear scale factor to an exponential factor, of the form

  $$CF = \alpha - \beta e^{-\gamma Q} \qquad \textbf{[11]}$$

  Based on fitting of the charging data curves to the equation detailed above. The parameters for α, β and γ are determined by fitting to three pairs of (Q, CF) coordinates determined by fits to experimental changing curves at different heating rates.
- The total indirect heating saving is calculated from an alternative discharge temperature change calculation, run in parallel with the discharging calculation discussed above. This is done to separate the charging and discharging processes that occur simultaneously as the FGHRS discharges, and therefore recognises the extra charging heat being recovered during discharge.

There is also discussion of a delay in temperature reduction during discharge, due to the flow of residual water within the cold water side of the FGHRS which has heated up with the store during charging. This delay was not applied in the spreadsheet application of this method available to Kiwa.

As this method is a combination of the BRE method and Method 1, it carries all of the same fundamental issues (with regards to boiler output in extreme space heating cases, hot water run through and waste water savings) that each of those two methods do. Like Method 1, this exponential decay charging factor present in this method provides an upper limit to the overestimation of high space load overprediction, but overpredicts to a greater extent in the very low space heating cases.

Advantages

- Mathematical equations are used to fit lines to the heating, cooling and discharge test results which removes the need for data manipulation to calculate gradients
- Requires minimal update of current calculation spreadsheet
- Does not increase the burden of testing
- Partially compatible with existing data

Disadvantages

- Does not reflect the complex interaction between space heating and hot water production

- Still requires complex spreadsheet models to be created
- Attempts to fuse two separate methods, potentially causing inconsistencies
- Replacing linear load scaling function with a function that tends to some value may solve problem at high space heating loads but lead to unrealistic results and low or high space heating
- Little empirical data to support scale-up theory
- Testing is time consuming
- Tests are non-standard

4.2.3 Method 3 - Draft standard prEN13203-7 [9]

4.2.3.1 Summary

This standard details a procedure for measuring the gas consumption of a boiler fitted with FGHRS when delivering DHW and takes into account the instantaneous and deferred savings provided by the FGHRS. There are separate tests to measure the performance of the unit in summer mode and in winter mode where the energy content of the FGHRS is measured after having been charged by the boiler operating in space heating mode.

The standard then combines these two values based on a defined number of summer and winter days in the year to create an average daily gas consumption. Whilst the standard does not specify a method for calculating the savings attributable to the FGHRS on a monthly basis as is required by SAP, it may provide output that could be used as part of a further method to calculate these savings.

Gas consumption in summer mode ($Q_{gas,s}$)

The gas consumption of the boiler and FGHRS when producing hot water in summer mode is measured directly by carrying out a standard EN13203-2 tapping cycle test with the FGHRS installed.

Energy contribution of FGHRS store ($Q_{gas,indirect}$)

Two methods are given for calculating $Q_{gas,indirect}$, which gives the indirect heating energy from the FGHRS in winter conditions. The two available methods are the short test method and the 24-hour test method.

4.2.3.2 Short test method

This method models the energy transferred to the DHW over a 24 hour period by assuming there are a series of energy transfers with 4 possible values, depending on the length of the draw off and the period of which it was previously charged during space heating operation. Four tests are specified to define these values:

The energy transferred to a:

- short draw off after a long (30 min) charging period ($Q_{tappedsmall,1}$)

- longer draw off after a long charging period ($Q_{tappedlage,1}$)
- short draw off after a short (15 min) charging period ($Q_{tappedsmall,2}$)
- longer draw off after a short charging period ($Q_{tappedlarge,2}$)

The total energy contribution over the day is then estimated by adding different numbers of the 4 different energy transfers, given by the following formula:

$$Q_{indirect} = (a.Q_{tappedsmal,1} + b.Q_{tappedlarge,1} + c.Q_{tappedsmall,2} + d.Q_{tappedlarge,2}) \qquad \textbf{[12]}$$

Where a, b, c and d are parameters based on the size of the tapping and the wait time from the charging period. These are taken from table 8 in the standard and are different for each of the M, L, XL, XXL, 3XL, 4XL tapping cycles.

Advantages:

- Only 4 tests are required of short duration
- Improvement over EN13203-2 as the deferred energy savings of the FGHRS can be estimated
- Method is presented as an extension of EN13203-2, aiming for a more seamless calculation between the methods.

Disadvantages

- Does not reflect the dynamic operation of the boiler. The charging tests are carried out at fixed flow and return temperatures
- Space heating operation is only at 30% part load with low flow and return temperatures (43/37°C). This could be seen as underestimating the potential charge in a FGHRS achieved by the period of space heating and thus the savings realised
- Only 2 levels of charge within the FGHRS are modelled
- Incompatible with SAP currently – requires further modelling to develop appropriate SAP inputs
- If the unit under test fails the thermal bridge test (or can’t be tested because there is no access to measure the intermediate temperature ‘X’) then this standard should not be used and there would be no means of testing these units, despite the fact they may indeed be FGHRS in other respects

4.2.3.3 24-hour test method

This method is based on a standard EN 13203-2 test and subjects the boiler to a similar pattern of draw offs, however the boiler burner is deactivated during the draw off. Additionally, the boiler is set to operate in space heating mode between draw offs and between the hours of 06:00 and 21:30.

The draw offs are started at the times stated in the load profile and the increase in temperature above ambient is used to calculate the energy transferred from the FGHRS to the water during each draw off.

The energy transferred from the FGHRS over the course of the day is equal to the sum of the energy transferred to the water during each draw off.

Advantages:

- Uses a very similar empirical method to a well-established (EN 13203-2) standard
- Test captures the varying levels of charge in the FGHRS due to the varying amount of space heating achieved between each draw off.

Disadvantages

- As with the 4 short tests, when in space heating mode the boiler only operates at 30% part load, 43/37°C. In reality the behaviour of the flow and return temperatures is likely to be dynamic
- Incompatible with SAP currently – requires further modelling to develop appropriate SAP inputs
- If the unit under test fails the thermal bridge test (or can't be tested because there is no access to measure the intermediate temperature 'X') then this standard should not be used and there would be no means of testing these units, despite the fact they may indeed be FGHRS in other respects

4.2.4 Method Comparison

Table 1 below shows a summary of the findings of the review of modelling methods for SFGHRS performance.

Table 1: Comparative notes on both the current method and the identified alternative methods for SFGHRS modelling

	Strength	Weakness	Risks	Testing burden
Current method	Is compatible with SAP in its current form	Complex spread sheet required to model the behaviour over 24 hours Case by case data manipulation required to make spread sheets stable	Different technologies managed by different organisations Data manipulation has been thought to disadvantage devices with storage	1 x changing test 1 x discharge test 1 x cooling test 2 x 13203-2 test Or 1 x 13203 test (for instantaneous FGHRS)

	Strength	Weakness	Risks	Testing burden
		Fixed flow/return temperatures and boiler output		
Method 1 (Closed form analytical solution)	Provides a consistent method to determine gradients for cooling, charging and discharging	Non-linear function used to relate space heating consumption to energy savings, may cause unrealistic values at low loads Fixed flow/return temperatures and boiler output	Lack of supporting data to justify how curve fits change with house heat demand	No additional tests over and above current method
Method 2 (Interim exponential method)	Allows for improvement of worst aspects of current method, without significant change	Non-linear function used to relate space heating consumption to energy savings, may cause unrealistic values as low loads Fixed flow/return temperatures and boiler output	Lack of empirical data to support exponential charge factor variation	No additional tests over and above current method
Method 3 (EN13203-7)	Integrated method with standard boiler testing (EN 13203). If testing done using short test method for ErP, then results can be calculated for any heat load profile and could thus provide data for PCDB and ErP with a single test.	Fixed flow and return temperatures during space heating operation may not reflect true level of charge in FGHRS. Temperatures are lower than SAP currently uses for PCDB entry tests. May exclude FGHRS which don't or can't complete	Unproven; standard is still in draft (at time of writing). Do test methods achieve same result. Not compatible with current SAP data - would need completely different methodology for SAP inclusion	1 x 13203-2 test and 4 short tests Or 1 x 24 hour test

	Strength	Weakness	Risks	Testing burden
		thermal bridge test.		

5 Laboratory Testing of FGHRS on the DHLTR

5.1 Test programme

The current method and closed form analytical solution method (Method 1) do not directly measure the performance of the FGHRS when the boiler is operating in space heating mode. Both methods aim to model the behaviour of the FGHRS over the course of a day based on standard tests, thermodynamic properties of the FGHRS and physical equations and assumptions. The closed form solution provides a method for resolving some of the inconsistencies of the current method.

Although the testing in PrEN13203-7 provides an improvement in terms of measuring the performance of the FGHRS with the boiler operating in space heating mode, it and all the previously mentioned methods do not reflect the variable level of charge that could be contained within the FGHR depending on variable flow and return temperatures that would be present with the boiler operating dynamically.

In order to determine how well the methods reflect reality, some kind of dynamic testing is required.

The most realistic type of performance test would be to carry large scale field trials of properties with many different types of boilers initially without FGHRS fitted, and then with them fitted. The next best thing would be to test the FGHRS under conditions that represent the heating/DHW load on the property every month throughout the year.

A test programme was devised that would test the boiler plus FGHRS under conditions that would be typical in summer, spring, winter and cold winter. The boiler with no FGHRS would be tested at summer conditions to provide a baseline performance, the assumption being that the standard boiler does not have any savings in generating DHW when used in conjunction with the space heating.

5.2 Test appliances

Test appliances were donated by stakeholders with an interest in this project.

The items available for test were a boiler with an integrated instantaneous FGHRS (no store) along with a (nearly) equivalent boiler with no FGHRS.

A second boiler from a different manufacturer was also received along with an add-on storage FGHRS unit.

This combination of units allowed testing of the baseline of boiler only performance and then the enhanced performance when then FGHRS devices were deployed.

5.3 Testing on the DHLTR

5.3.1 Test setup and configuration of model

Kiwa's Dynamic Heat Load Test Rig (DHLTR) has been specifically designed to provide realistic space heating loads for a wide variety of property types and has been extensively used in comparative trials of new technology for many clients. It provides an accurate and repeatable daily heating load for space heating, using a combination of software and hardware in the loop. In this case, it has been used in conjunction with Kiwa's Efficiency test rig (ETR) which has provided the precise DHW demand (load profile) required for these tests, based on the standard EN13203-2. The 2 rigs were synchronised to provide hot water and heating using the same time schedules. The test rig setup is shown in Figure 3 below:

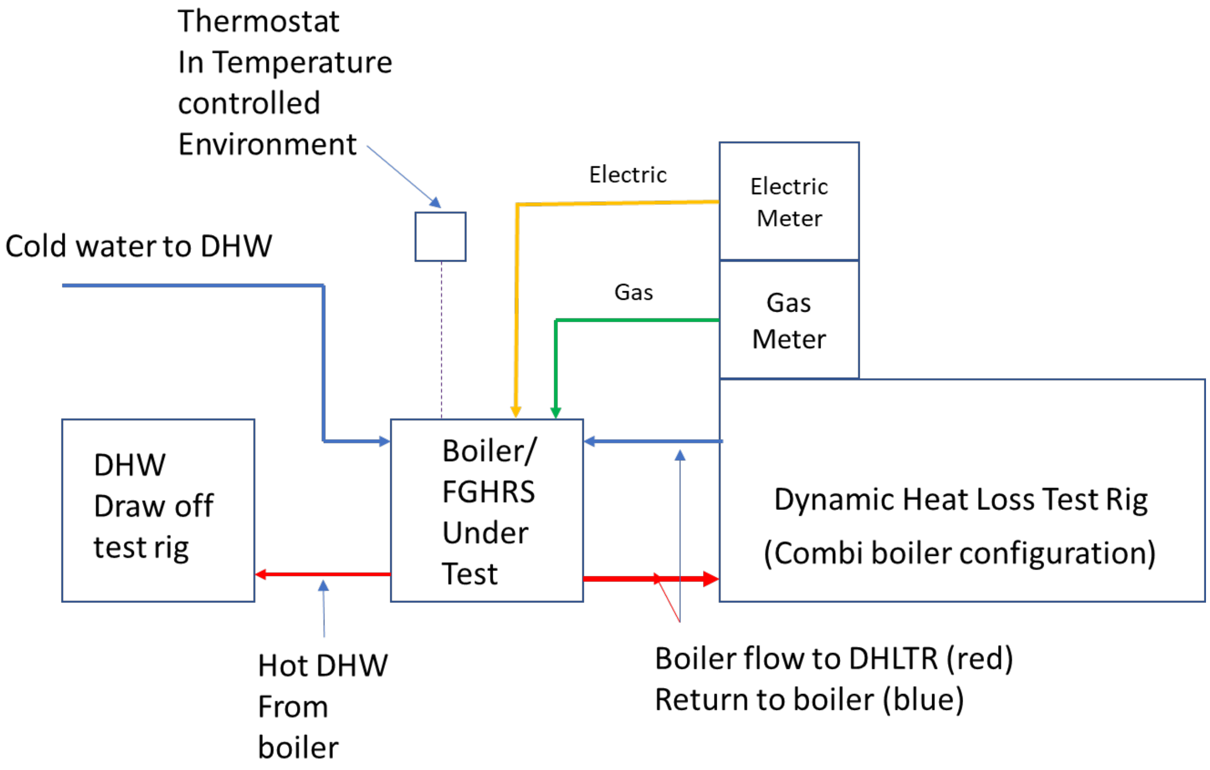


Figure 3: Test rig setup

The test conditions were chosen to represent the performance of FHGRS in typical installations, but with other more favourable characteristics, such as high temperature radiators and high CH flow temperatures. Similarly, heating periods have been chosen to represent likely practice, so bimodal heating in spring/autumn, unimodal in colder periods/weekends, and fully on during extreme winter conditions. These conditions should generate the best realistic case for FGHRS but may lead to higher estimated savings than are possible if low-temperature systems, such as low temperature radiators or underfloor heating are employed.

Property sizes

The property sizes were chosen to represent a range around the UK average property. Properties with heat losses of 105, 300, 500 W/K were chosen as representing the majority of UK housing stock.

The ‘thermal mass’ of each was based on data obtained from the SAP calculations performed for these properties (and detailed in section 5.7), this is the SAP thermal mass parameter times the floor area.

For each of these properties, design work was carried out to calculate a suitable radiator area and system water volume. This work was based on the CIBSE Domestic Heating Design Guide [18] using a design temperature of -2°C and an indoor temperature of 21°C. The radiators chosen for this were normal high temperature radiators and flow and return temperatures chosen to match test temperature conditions (65°C flow temperature and approximately 10-15K temperature drop). System water volume was calculated from the required number of radiators plus an allowance for pipework volumes, and an additional amount to represent the thermal load of the metal in the system.

The temperature within the simulated property is controlled by a physical electronic thermostat located in a temperature-controlled enclosure, which tracks the internal temperature of the property. This thermostat was set at 21°C for all the tests undertaken in this project.

Outdoor temperature profiles

Four outdoor temperature profiles were chosen, these being: Summer (average July), Spring (average April), Winter (average February), Cold winter.

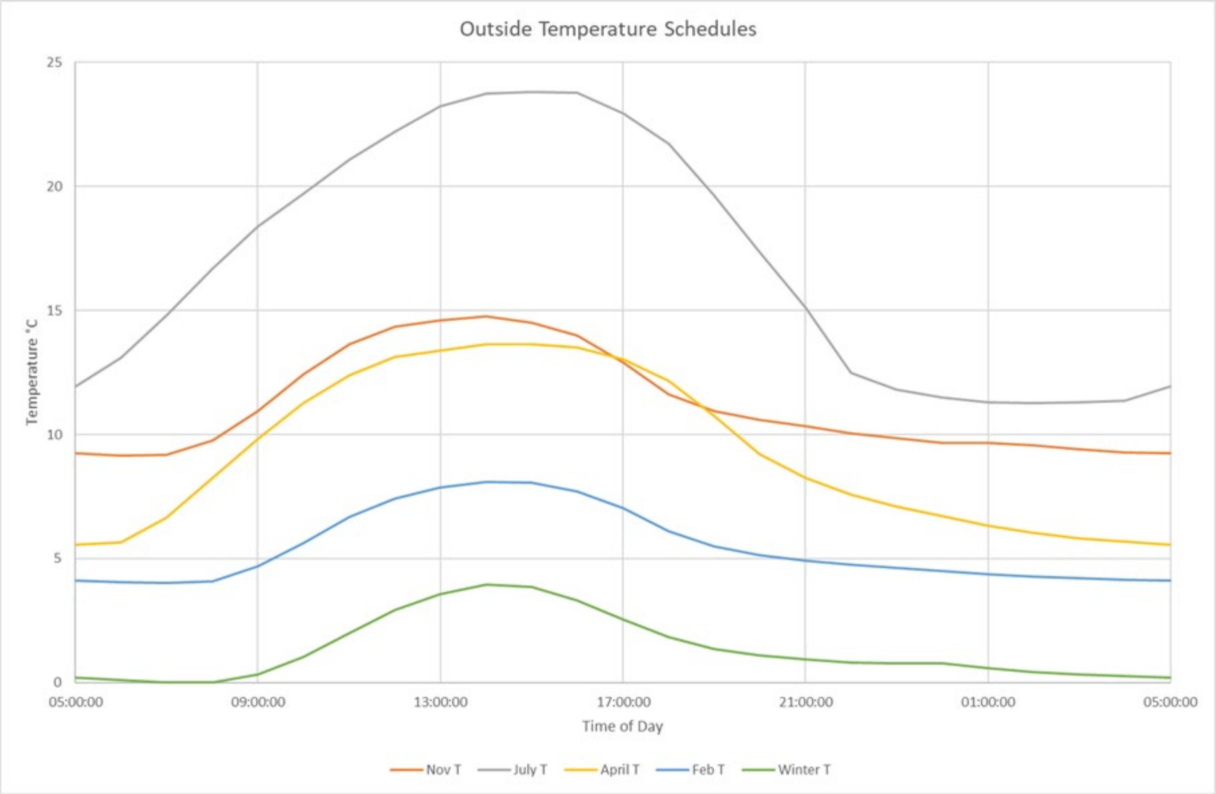


Figure 4: Outdoor temperature profiles used for tests (November profile not used in these tests)

The average daily temperatures for the 4 profiles used from Figure 4 were:

Summer (July)	17.09°C
Spring (April)	9.4°C
Winter (February)	5.5°C
Cold Winter	1.38°C

During test work the DHW inlet temperature is maintained at 10°C ± 2°C as per EN13203-2, to allow comparison of results with standard DHW tests.

Space heating demands

The space heating profiles were chosen to match the outdoor temperature profile (season).

- Summer – no heating
- Spring – bimodal (heating on 07:00-09:00 and 16:00-23:00)
- Winter – unimodal (heating on 07:00-23:00)
- Cold winter – continuous (heating on fully, all day)

Note that although the heating is enabled during the times indicated above, it is controlled by the demand from a room thermostat (set at 21°C).

DHW loads

The chosen DHW load profiles were all based on EN13203-2/ErP Standards.

- ‘M’ load profile was used for all property sizes.
- ‘S’ load profile for 105W/K.
- ‘L’ load profile for 300W/K and 500W/K.

5.3.2 Technologies investigated

- Instantaneous FGHRS + equivalent combination boiler without FGHRS
- Non-integral Storage FGHRS tested and base combination boiler by itself.

5.3.3 Methodology

In each case the base boiler alone was tested without FGHRS at summer conditions, with the appropriate DHW load profiles. This allowed determination of the gas use for DHW and hence efficiency, it would be expected that these results mirror those done to EN13203-2. These tests results provide a baseline to which all subsequent testing is compared. Additionally, for one of the test boilers, a single test with winter conditions was also completed for comparison with the summer test result to investigate how much space heating operation affected DHW production on a standard combination boiler.

The boiler was then fitted with FGHRS/ or replaced with integrated boiler/FGHRS according to the manufacturer's instructions. In the case of the storage FGHRS the manufacturer specified a mixing valve be installed between the FGHRS outlet and the boiler DHW inlet, this was set at 30°C, mixing cold water with the output of the FGHRS.

Both FGHRS were tested at all appropriate property sizes and all appropriate DHW load profiles, as shown in the test matrix (Table 2, Table 3 and Table 4)

Following each test, the data were analysed and the split of gas use between space heating and DHW was determined. Savings attributable to the FGHRS were calculated, and efficiency of DHW production was also calculated.

Results with and without FGHRS were compared to determine efficiencies/savings over the range of property heat demands studied.

Please note that all calculations used in this work are based on the Gross Calorific Value (GCV) of the test gas.

For each test, the rig temperatures were allowed to stabilise at the required start temperature for the property and experimental external conditions demanded. The start temperature of the boiler/CH water and internal property temperature were calculated assuming the temperature at 23:00 was 21°C, the decay of temperature was predicted until the test start time of 05:00. This temperature was applied to the environment chamber housing the room thermostat and the bulk water temperature of the CH circuit. However, as the boiler and FGHRS were exposed to the laboratory environment temperature these were stabilised at that temperature (20°C±2°C). For continuous heating tests, the heating system was heated until the temperature was 60°C at the boiler return and it was assumed the room temperature was 21°C at this point and the environment chamber was set at that temperature. The start time of 05:00 was chosen as the conditions with both intermittent and continuous operation, would be closely matched from start to end of test, thus avoiding anomalies in results due to changes in stored energy. Tests on the DHLTR are designed to give excellent comparative results when comparing different technologies, and have been proven to give accurate performance assessments over hundreds of tests over the past 16 years, many of which have been compared to field trials and matched pair house tests, to confirm the validity of the methodology and equipment.

The tapping tests are based on EN13203-2 and use the same water temperature, flowrate conditions, timings, and temperature requirements as that standard.

Test matrix

S= 2.1 kWh/day DHW heat load profile

M=5.845 kWh/day DHW heat load profile

L=11.655 kWh/day DHW heat load profile

Table 1: 300W/K property – DHW load profile tests carried out

Outdoor temperature profile	Base boiler 1	Integral Instantaneous FGHRS	Base boiler 2	Non-integral Storage FGHRS
Summer	M	M, L	M, L	M, L
Spring		M, L		M, L
Winter		M, L	M	M, L
Cold Winter		M, L		M, L

Table 2: 105W/K property – DHW load profile tests carried out

Outdoor temperature profile	Base boiler 1	Integral Instantaneous FGHRS	Base boiler 2	Non-integral Storage FGHRS
Summer			S, M	S, M
Spring				S, M
Winter				S, M
Cold Winter				S, M

Table 3: 500W/K property – DHW load profile tests carried out

Outdoor temperature profile	Base boiler 1	Integral Instantaneous FGHRS	Base boiler 2	Non-integral Storage FGHRS
Summer			M, L	M, L
Spring				M, L
Winter				M, L
Cold Winter				M, L

Total 40 tests

Table 4:Boiler data from manufacturer literature and PCDB

	Fuel	Max CH output (kW)	SAP Heating Efficiency *(%)*	Max DHW output (kW)	SAP comparative hot water efficiency *(%)*
Base boiler 1	Natural Gas	24.2	91.1	30.3	70.4
Integral Instantaneous FGHRS	Natural Gas	24.2	91.1	30.4	85.9
Base boiler 2	Natural Gas	25	90.2	36	81.4
Non-integral Storage FGHRS	Natural Gas	25	90.2	NA	NA

NA – not available

5.4 Testing to EN13203-7

Additional tests were carried to the draft EN130203-7 standard [9], which is specifically designed to determine the annual performance of boilers with FGHRS for ErP purposes.

This was investigated as a possible route to providing a new universally employed method to determine the performance of FGHRS under SAP 10 and future versions of SAP.

Tests were done using the draft standard as it stands (using the short test method) and also using the same method but with elevated charging temperatures.

The draft method appears to exclude load profiles of less than ‘M’ size, which may be the result of a typographical error. We have extended it down to ‘S’ to allow comparison with the data obtained in the experiments using the DHLTR. The draft also contained a number of errors in Table 8 where the number of parameters for the M and L load profiles were incorrect and also some were mis-categorised, we have also corrected these, as we believe they should be allocated.

These tests were only done on the non-integral storage FGHRS boiler combination, as this was the only system that we were able to configure for this test.

5.5 Test results

5.5.1 DHLTR Test Results

Figures 5 and 6 below show a typical 24 hour test profile, for a bimodal heating pattern on the 300W/K property. The bimodal heating pattern can be observed from the flow and return temperatures of the boiler and the gas use. The points where the DHW draw-offs occur are also clearly visible as peaks in DHW exit temperature and gas use.

Boiler+non-integrated FGHRS Temperatures, Bimodal April 300WK DHW ‘M’

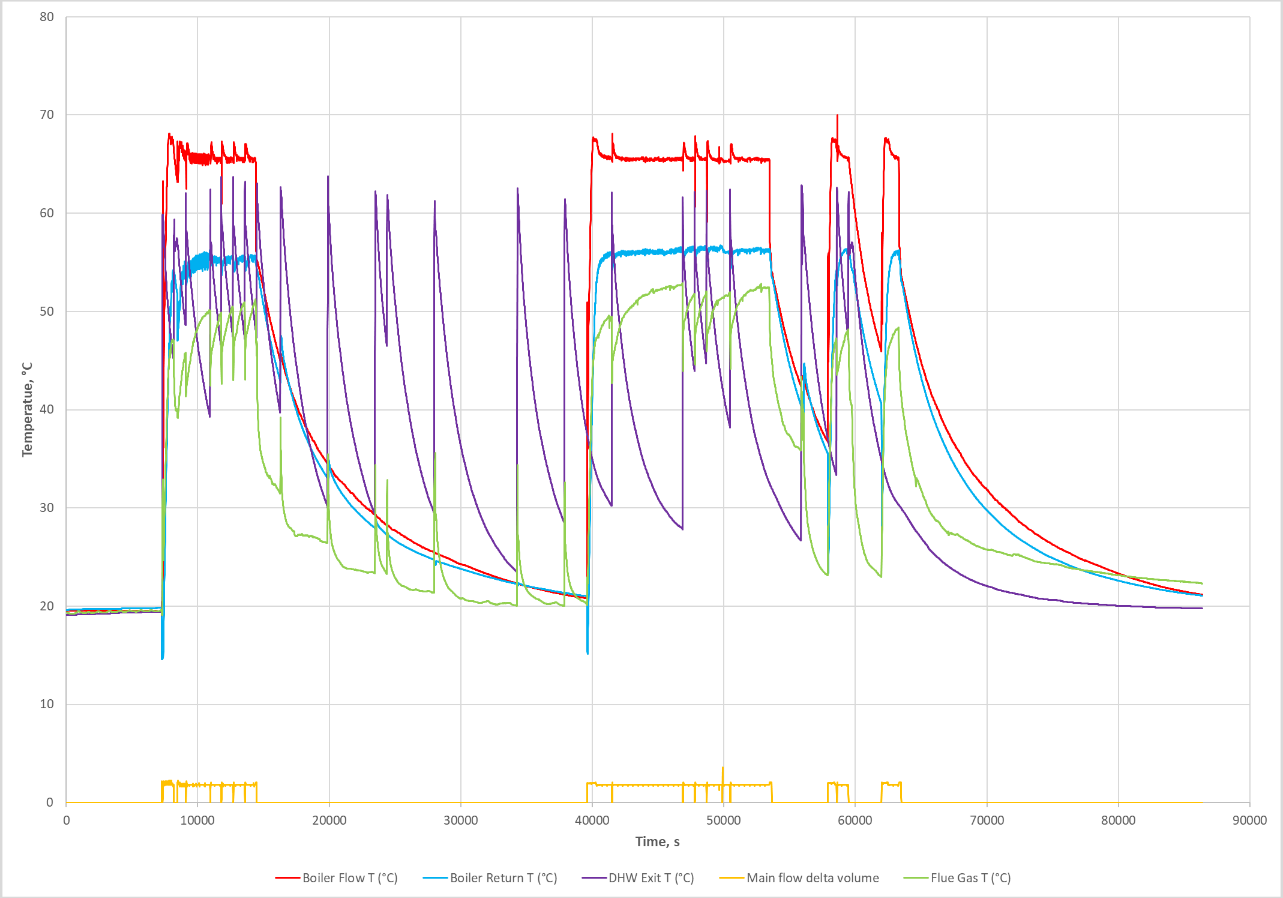


Figure 5: Typical 24- hour test profile boiler temperatures

Boiler+non-integrated FGHRS Environment Temperatures/ Power Use Bimodal April 300WK DHW ‘M’

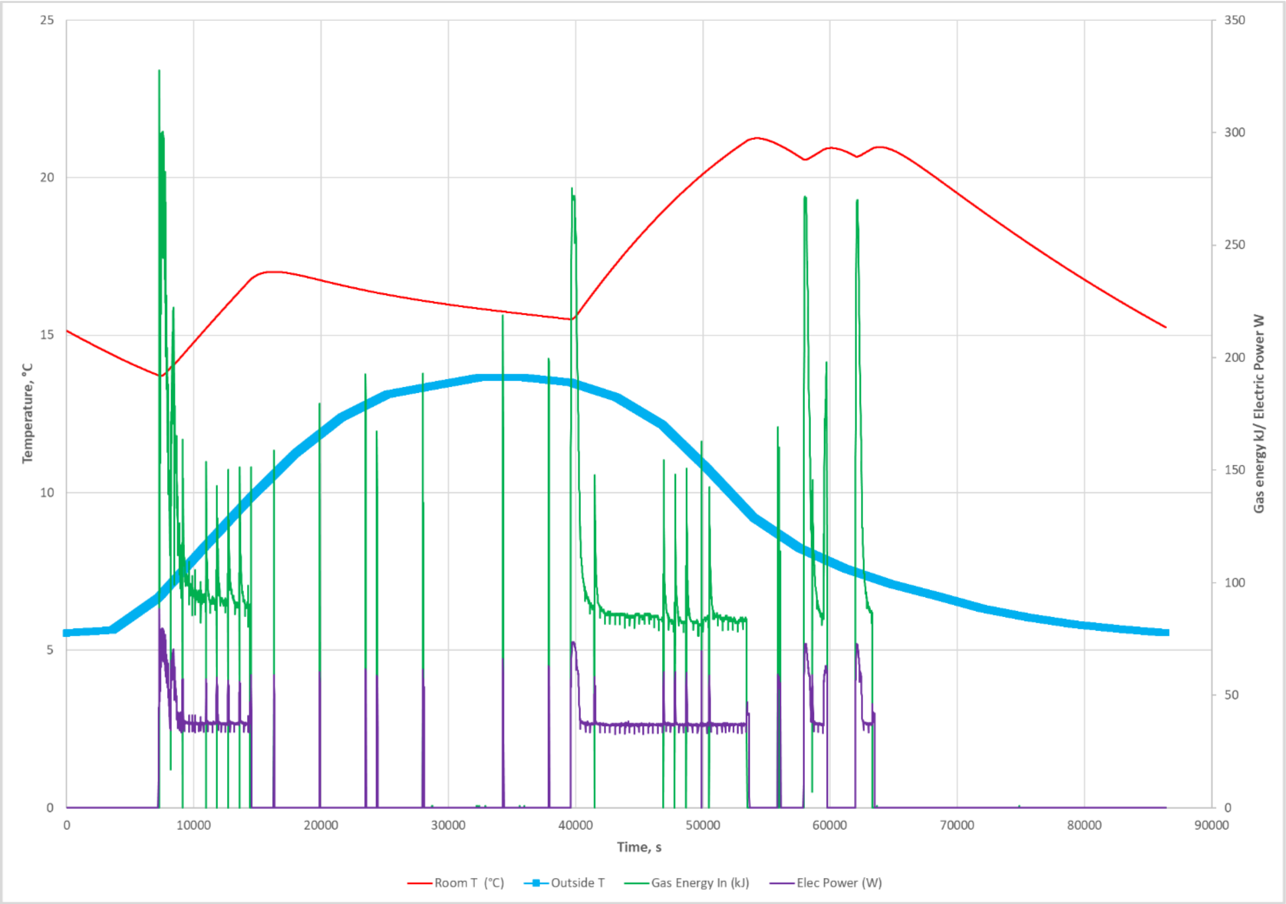


Figure 6: Typical 24-hour test profile environment temperatures / energy use

Tables 6 to 9 summarize the important data obtained from the tests completed

Table 6: 300W/K heat loss rate property tests - Integral Instantaneous FGHRS

Boiler (B) or FGHRS (F)	Heat load profile	Heat load profile	DHW profile	Total gas use kWh/ day	DHW gas use kWh/ day	SH load kWh/ day	DHW load kWh/ day	Int. T avg. °C	Ext. T avg. °C	Avg. heat loss* W
B	July	None	M	8.56	8.56	0.00	5.86	17.88	17.09	236
F	July	None	M	7.46	7.46	0.00	5.85	17.88	17.09	236
F	April	Bi	M	85.90	6.78	66.45	5.84	17.85	9.40	2536
F	Feb	Uni	M	117.66	6.54	93.73	5.84	18.44	5.50	3881
F	Winter	Cont	M	157.74	6.44	126.64	5.84	20.81	1.38	5831
B	July	None	L	-	-	-	-	-	-	-
F	July	None	L	13.46	13.45	0.00	11.67	17.88	17.09	235
F	April	Bi	L	83.39	13.21	59.13	11.66	17.75	9.40	2505
F	Feb	Uni	L	111.20	12.88	82.84	11.65	18.40	5.50	3870
F	Winter	Cont	L	155.59	12.36	119.34	11.65	20.77	1.38	5817

NB: Bi = bimodal heating regime, Uni = unimodal heating regime, Cont = continuous 24 hour heating regime, None = no space heating SH=Space Heating.

* of simulated property

Table 7: 300W/K heat loss rate property tests - Non-integral Storage FGHRS

Boiler or FGHRS	Heat load profile	Heat load profile	DHW profile	Total gas use kWh/ day	DHW gas use kWh/ day	SH load kWh/ day	DHW load kWh/ day	Int. T av °C	Ext.T Av °C	Av heat loss * W
B	July	None	M	7.86	7.85	0.00	5.86	17.88	17.09	236
B	Feb	Uni	M	117.75	6.94	93.36	5.85	18.46	5.50	3888
F	July	None	M	7.19	7.19	0.00	5.85	17.88	17.09	235
F	April	Bi	M	73.40	5.37	56.78	5.85	17.42	9.40	2407
F	Feb	Uni	M	110.17	4.97	88.11	5.85	18.29	5.50	3838
F	Winter	Cont	M	159.23	4.69	130.85	5.84	20.78	1.38	5821
B	July	None	L	14.39	14.39	0.00	11.68	17.87	17.09	235
F	July	None	L	13.34	13.33	0.00	11.66	17.88	17.09	235
F	July	None	L	13.46	13.46	0.00	11.66	17.88	17.09	236
F	April	Bi	L	79.63	12.03	56.98	11.66	17.46	9.40	2418
F	Feb	Uni	L	114.87	11.45	87.70	11.66	18.48	5.50	3895
F	Winter	Cont	L	169.47	10.75	134.15	11.65	20.85	1.38	5841

* of simulated property

Table 8: 105W/K heat loss rate property tests - Non-integral Storage FGHRS

Boiler or FGHRS	Heat load profile	Heat load profile	DHW profile	Total gas use kWh/ day	DHW gas use kWh/ day	SH load kWh/ day	DHW load kWh/ day	Int. T av °C	Ext.T Av °C	Av heat loss * W
B	July	None	S	3.38	3.38	0.00	2.14	17.89	17.09	79
F	July	None	S	3.06	3.05	0.00	2.13	17.87	17.09	78
F	April	Bi	S	32.99	1.95	23.93	2.12	17.93	9.40	854
F	Feb	Uni	S	47.40	1.53	35.65	2.11	18.62	5.50	1312
F	Winter	Cont	S	69.83	1.31	53.92	2.11	20.80	1.38	1942
B	July	None	M	7.86	7.85	0.00	5.86	17.88	17.09	79
F	July	None	M	7.19	7.19	0.00	5.85	17.88	17.09	78
F	April	Bi	M	38.73	5.27	26.15	5.85	17.72	9.40	833
F	Feb	Uni	M	55.85	4.95	40.25	5.85	18.58	5.50	1308
F	Winter	Cont	M	75.62	4.77	56.30	5.84	20.78	1.38	1940

* of simulated property

Table 9: 500W/K heat loss rate property tests - Non-integral Storage FGHRS

Boiler or FGHRS	Heat load profile	Heat load profile	DHW profile	Total gas use kWh/ day	DHW gas use kWh/ day	SH load kWh/ day	DHW load kWh/ day	Int. T av °C	Ext. T av °C	Av heat loss * W
B	July	None	M	7.86	7.85	0.00	5.86	17.88	17.09	393
F	July	None	M	7.31	7.30	0.00	5.85	17.88	17.09	394
F	April	Bi	M	111.66	6.16	92.66	5.85	17.20	9.40	3902
F	Feb	Uni	M	178.43	5.38	151.02	5.85	18.32	5.50	6409
F	Winter	Cont	M	265.56	5.27	226.67	5.84	20.89	1.38	9759
B	July	None	L	14.39	14.39	0.00	11.68	17.87	17.09	392
F	July	None	L	13.46	13.46	0.00	11.66	17.87	17.09	392
F	April	Bi	L	116.59	12.16	91.47	11.66	17.14	9.40	3872
F	Feb	Uni	L	182.12	11.89	149.08	11.66	18.21	5.50	6353
F	Winter	Cont	L	266.32	11.19	221.59	11.65	20.87	1.38	9747

* of simulated property

FGHRS Performance compared to base boiler

The data obtained above have been analysed to obtain gas savings and efficiency improvements due to the use of FGHRS. All efficiencies have been calculated on a gross CV basis.

Efficiency is that of DHW production and is defined as:

DHW efficiency = Energy of DHW produced / Gas directly used in DHW production

Where:

‘Energy of DHW produced’ includes any energy recovered from the FGHRS store and is based on the procedures and calculations as presented in Sections 5.2 and 5.3 of EN13203-2.

Gas use is calculated as per Section 5.4 of EN13203-2 but is based on Gross Calorific Value and is only counted when there is a DHW demand.

Table 10:– 300W/K heat loss rate property – Instantaneous FGHRS, DHW “M” Load profile

Base boiler	Summer
Average base case gas for DHW, kWh/day	8.56
Average DHW load, kWh/day	5.86
DHW Efficiency %	68.40

Instantaneous FGHRS	Summer	April	Feb	Winter
DHW Efficiency	78.44%	86.08%	89.37%	90.66%

Instantaneous FGHRS	Summer	April	Feb	Winter
Gas saved compared to boiler, kWh/day	1.10	1.78	2.02	2.12
% saving of original gas use	12.82%	20.76%	23.64%	24.75%

Table 5: 300W/K heat loss rate property – Storage FGHRS, DHW “M” Load profile

Base boiler	Summer	Feb
Average base case gas for DHW, kWh/day	7.85	6.94
Average DHW load, kWh/day	5.86	5.85
DHW Efficiency %	74.58	84.42

Storage FGHRS	Summer	April	Feb	Winter
DHW Efficiency	81.39%	108.98%	117.63%	124.47%
Gas saved compared to boiler, kWh/day	0.66	2.48	2.88	3.16
% saving of original gas use	8.42%	31.59%	36.66%	40.26%

Table 6: 300W/K heat loss rate property - Storage FGHRS, DHW "L" Load profile

Base boiler	Summer
Average base case gas for DHW, kWh/day	14.39
Average DHW load, kWh/day	11.68
DHW Efficiency %	81.19

Storage FGHRS	Summer	April	Feb	Winter
DHW Efficiency	87.04%	96.95%	101.83%	108.43%
Gas saved compared to boiler, kWh/day	0.99	2.36	2.94	3.64
% saving of original gas use	6.88%	16.41%	20.41%	25.32%

Table 7: 500W/K heat loss rate property - Storage FGHRS, DHW “M” Load Profile

Base boiler	Summer
Average base case gas, kWh/day	7.85
Average DHW load, kWh/day	5.86
DHW Efficiency %	74.58

Storage FGHRS	Summer	April	Feb	Winter
DHW Efficiency	80.19%	94.97%	108.78%	110.84%
Gas saved compared to boiler, kWh/day	0.55	1.69	2.48	2.58
% saving of original gas use	7.04%	21.55%	31.53%	32.87%

Table 8: 500W/K Heat Loss Rate property - Storage FGHRS, DHW "L" Profile

Base boiler	Summer
Average base case gas, kWh/day	14.39
Average DHW load, kWh/day	11.68
DHW Efficiency %	81.19

Storage FGHRS	Summer	April	Feb	Winter
DHW Efficiency	86.64%	95.89%	98.07%	104.12%
Gas saved compared to boiler, kWh/day	0.93	2.23	2.49	3.20
% saving of original gas use	6.44%	15.48%	17.34%	22.23%

Table 9: 105W/K heat loss rate property - Storage FGHRS, DHW "M" load Profile

Base boiler	Summer
Average base case gas, kWh/day	7.85
Average DHW load, kWh/day	5.86
DHW Efficiency %	74.58

Storage FGHRS	Summer	April	Feb	Winter
DHW Efficiency	81.4%	111.1%	118.3%	122.4%
Gas saved compared to boiler, kWh/day	0.66	2.58	2.91	3.08
% saving of original gas use	8.4%	32.9%	37.0%	39.2%

Table 10: 105W/K heat loss rate property - Storage FGHRS, DHW "S" load Profile

Base boiler	Summer
Average base case gas, kWh/day	3.38
Average DHW load, kWh/day	2.14
DHW Efficiency %	63.53

Storage FGHRS	Summer	April	Feb	Winter
DHW Efficiency	69.6%	108.3%	138.2%	160.3%
Gas saved compared to boiler, kWh/day	0.32	1.42	1.85	2.06
% saving of original gas use	9.5%	42.1%	54.8%	61.1%

The gas savings due to use of FGHRS technology have been plotted against the property heat loss (in these tests, equivalent to the heat supplied by the space heating function of the boiler, Figures 7 to 12). It is also calculated on a monthly basis in the SAP procedure which allows the test results to be linked to the predictions made by SAP.

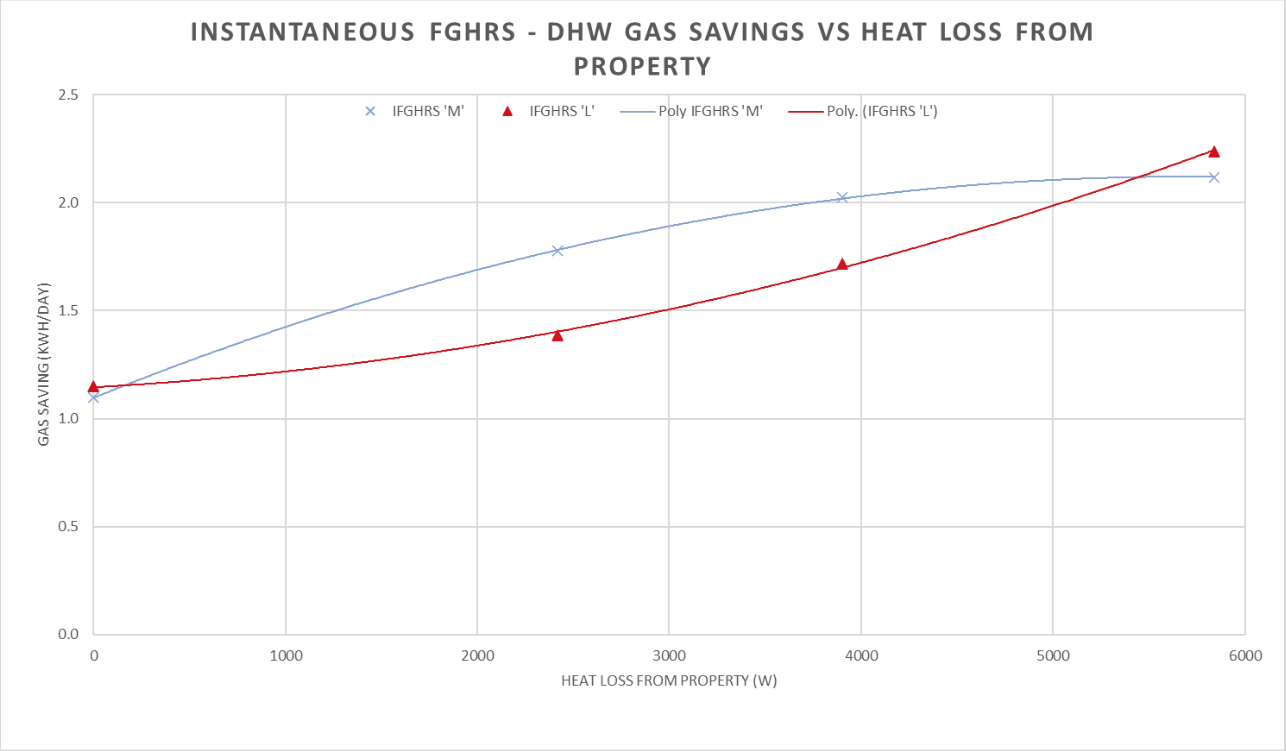


Figure 1: Gas saving compared to the original boiler DHW gas use vs. heat loss from property - IFGHRS

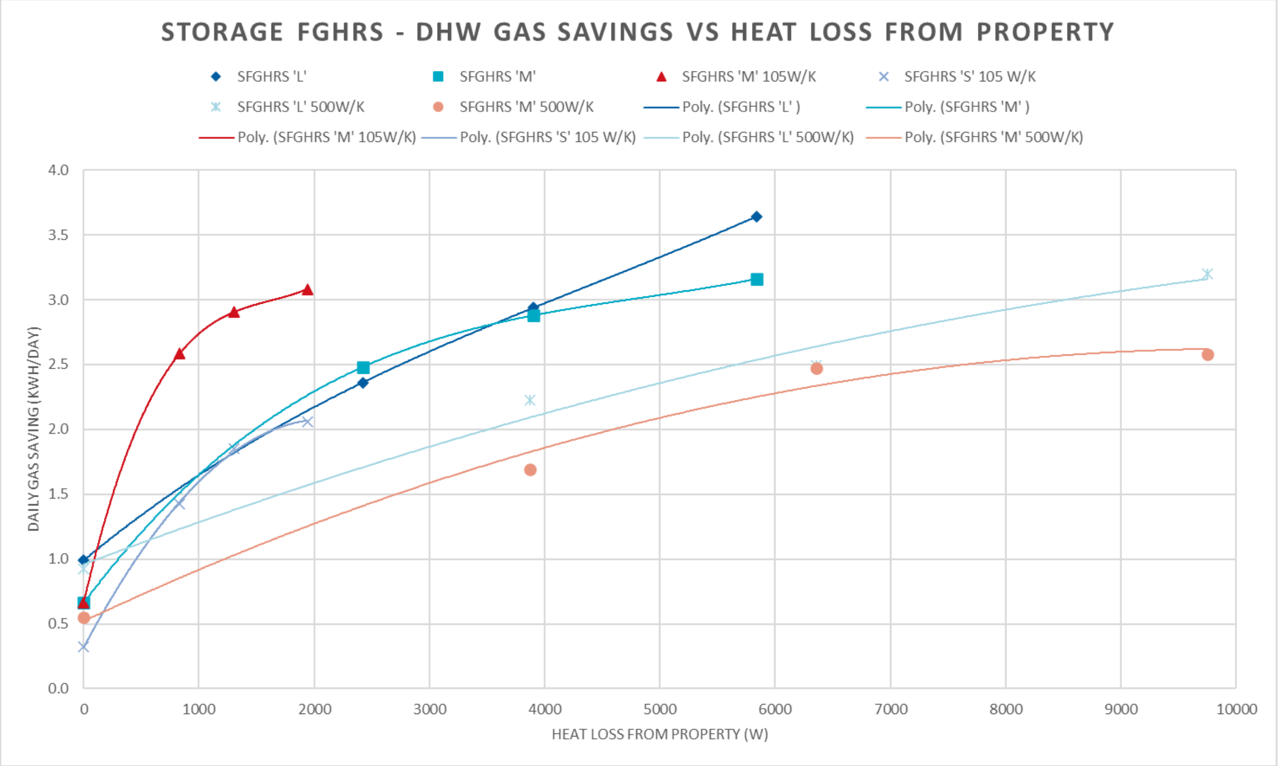


Figure 2: Gas saving compared to the original boiler DHW gas use vs. heat loss from property - SFGHRS

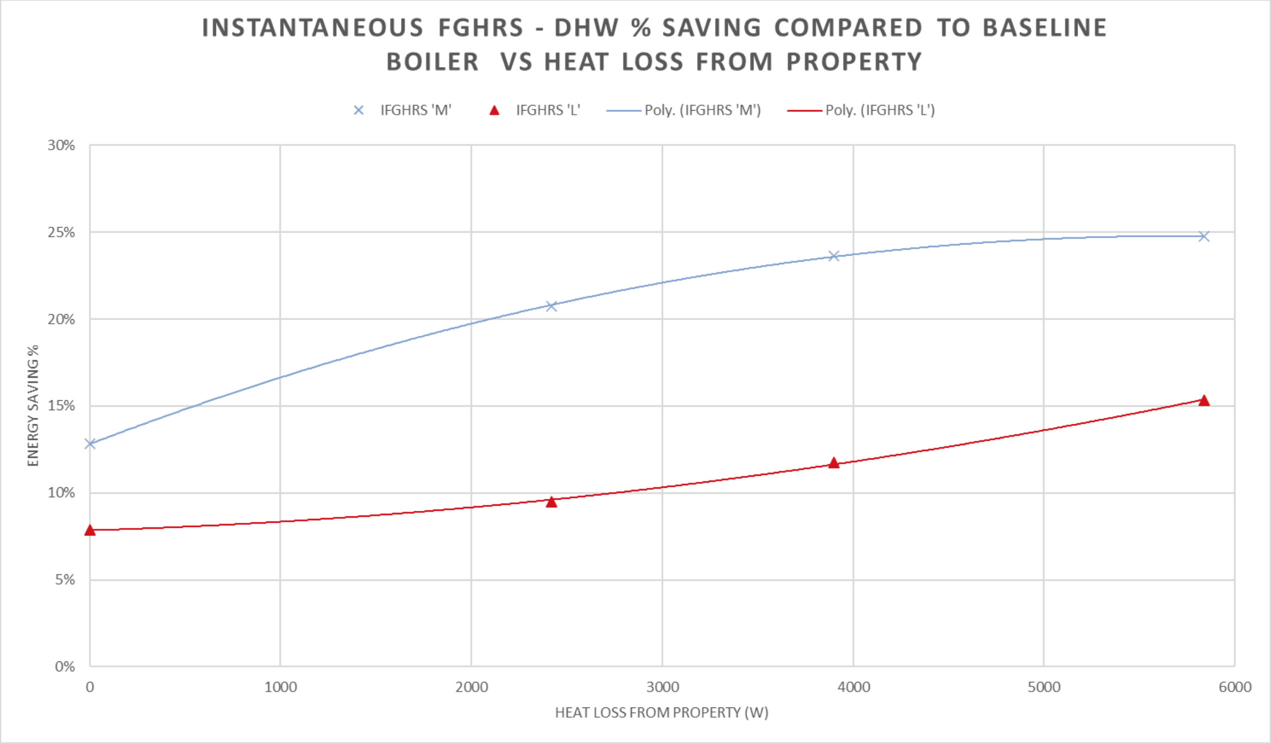


Figure 3: Gas savings as a percentage of the original boiler gas use vs. heat loss from property - IFGHRS

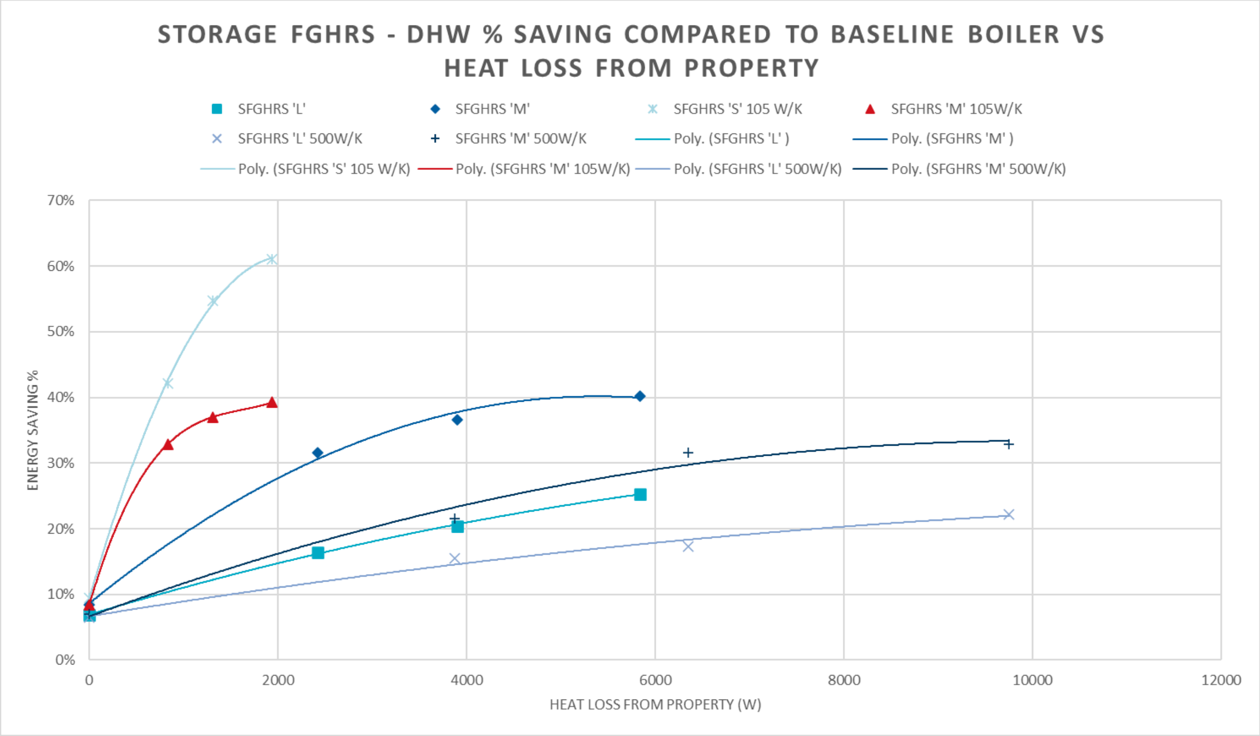


Figure 4: Gas savings as a percentage of the original boiler gas use vs. heat loss from property – SFGHRS

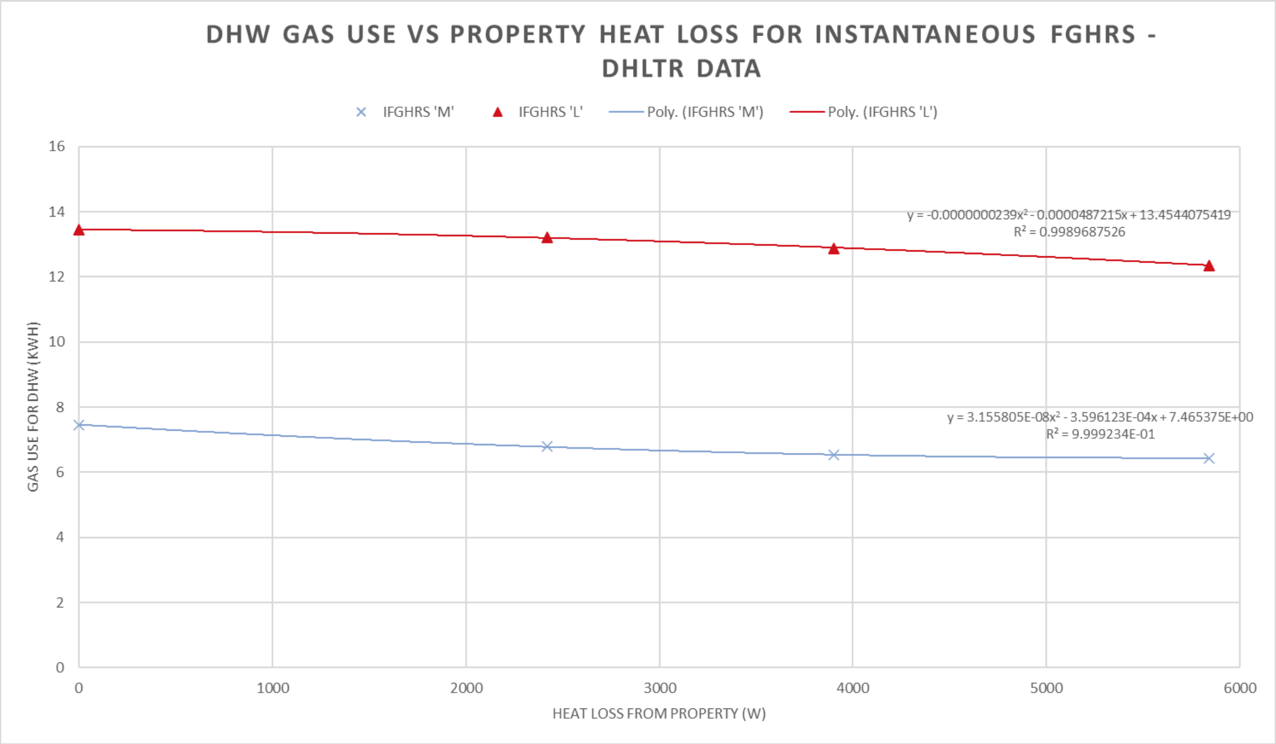


Figure 5: Gas use for DHW vs. heat loss from property - IFGHRS

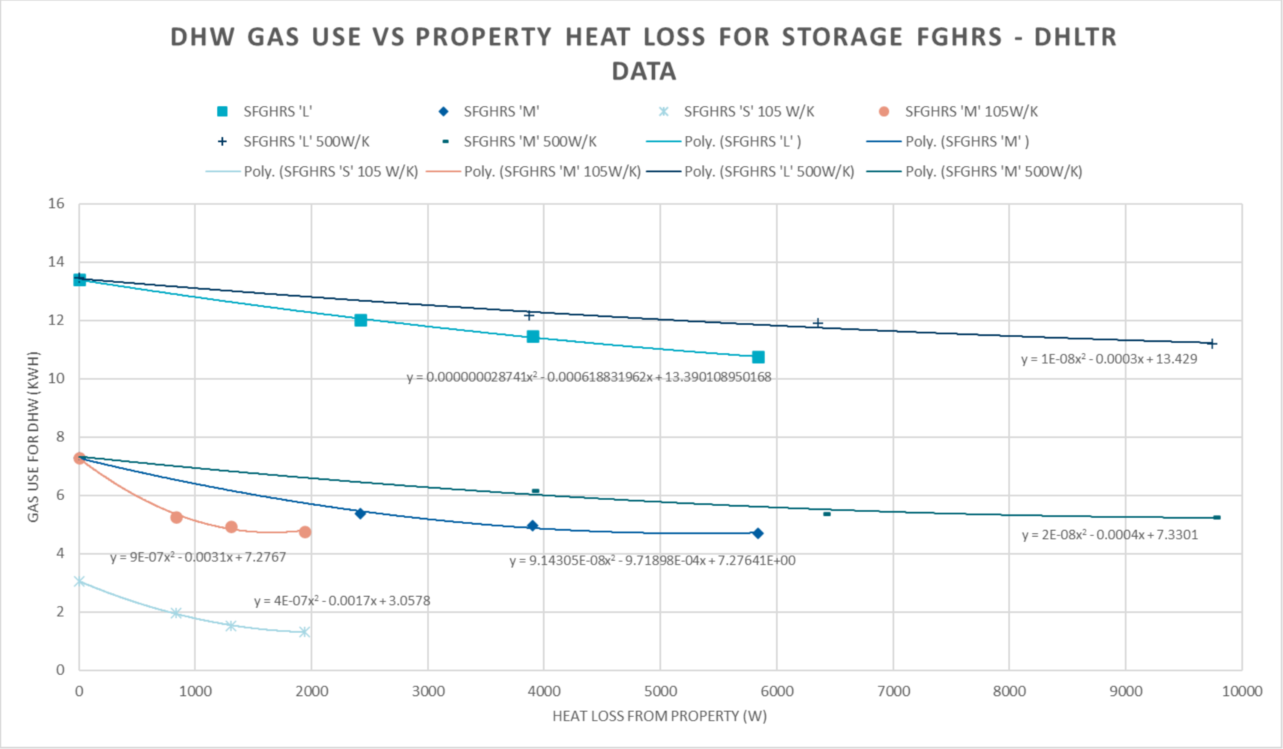


Figure 6: Gas use for DHW vs. heat loss from property - SFGHRS

The trendlines shown on Figure 11 and Figure 12 have been derived to enable prediction of the likely gas saving at various house heat loss rates. These are to be used in conjunction with SAP2012 analyses for each of the properties to calculate the gas saving as determined by experimental data as opposed to what the current SAP calculations predict.

Taking the 300 W/K property, which is a slightly larger heat demand than the UK average, and the storage FGHRS. The saving in gas used for producing DHW is at a maximum with the winter space heating load. Based on the ‘M’ tapping (which is approximately UK average DHW demand) then the saving is 3.16 kWh/day of gas. In the summer the saving is 0.66 kWh/day, from the data above.

Assuming a heating season of the 243 days (based on SAP) the **maximum estimated saving** in this configuration would be

= days in heating season x saving per day + days out of heating season x saving per day

=243 x 3.16 + 122 x 0.66 kWh = 848 kWh/year

For the gas boiler alone on the same basis the total DHW gas use would be 2865 kWh/year (from 365 x 7.85 kWh/day for boiler alone in summer mode)

And therefore, the total gas demand for DHW production for the boiler + FGHRS would be estimated at 2017 kWh/year (from 2865 – 848 kWh/year), saving approximately 30%

If we consider a smaller/better insulated house but still with average DHW demand (ie 'M' DHW load profile) based on the above data the saving is 829 kWh/year, a saving of 29%.

If the DHW load is reduced to the S DHW load profile then the saving is 540 kWh/year compared to a base boiler gas use of 1234 kWh/year, a saving of 44%. However, it must be noted that this DHW load is for only 36 L, which is well below the average usage and also below what SAP would estimate DHW usage would be for a property occupied by a single person.

However, the above figures give an indication of the maximum likely savings that could be achieved using these items under test and conditions used. As a guideline figure, these data would indicate an upper level potential saving of around 30% of gas used for DHW production per annum for properties with average DHW loads. Many factors will affect this figure, in particular heating demand is unlikely to be at maximum load all throughout the heating season and DHW demand also varies throughout the year. A more complete analysis is given in the section 5.7 on SAP predictions.

One way of visualising the energy flows around the boiler system is via Sankey diagrams. These diagrams provide a visual reference of the relative magnitude of the energy flows into and out of the boiler system. The energy flows were calculated from the experimental test data, by performing an energy balance on the combined boiler-FGHRS system. This approach uses a number of assumptions to complete the picture. A couple of points of note:

- There are no flows present for condensation within the boiler internal condenser. This is due to the calculated humidity in the flue gas being lower than the saturation concentration at the flue gas leaving temperature (assumed to be the highest temperature seen in the empirical data). This flow of energy is cyclical within the boiler-FGHRS system (i.e. it is energy that is immediately recovered)
- There is no flow present for indirect heating of the FGHRS store by the ambient conditions. This is due to a lack of measured data of this particular parameter, and so was not considered in the energy balance. Given that the major sources of energy outflow are considered in this study, it could be considered that any heat gained from this energy source ultimately adds to the losses seen.
- Losses are calculated both from the case and as unaccounted energy loss within the flue system.

- The diagrams use the following colour coding:
  - Blue – inlets
  - Red – outlets
  - Yellow – hot water outlet
  - Green – recycled/internal flows
  - Orange – total heat in the system

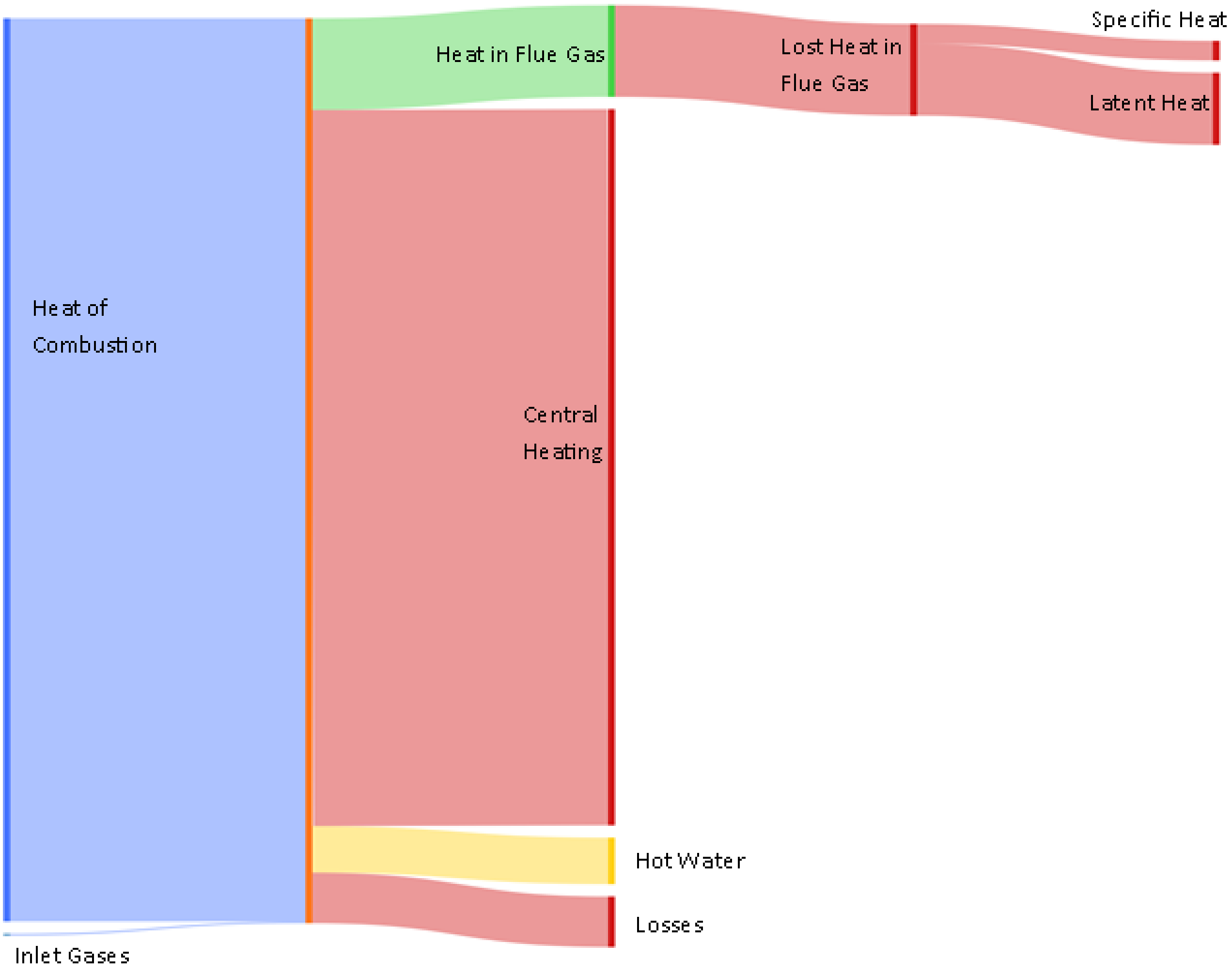


Figure 7: Sankey diagram of the total energy flows (summed over the 24 h experiment run time) for the boiler only, run under a February M tapping test

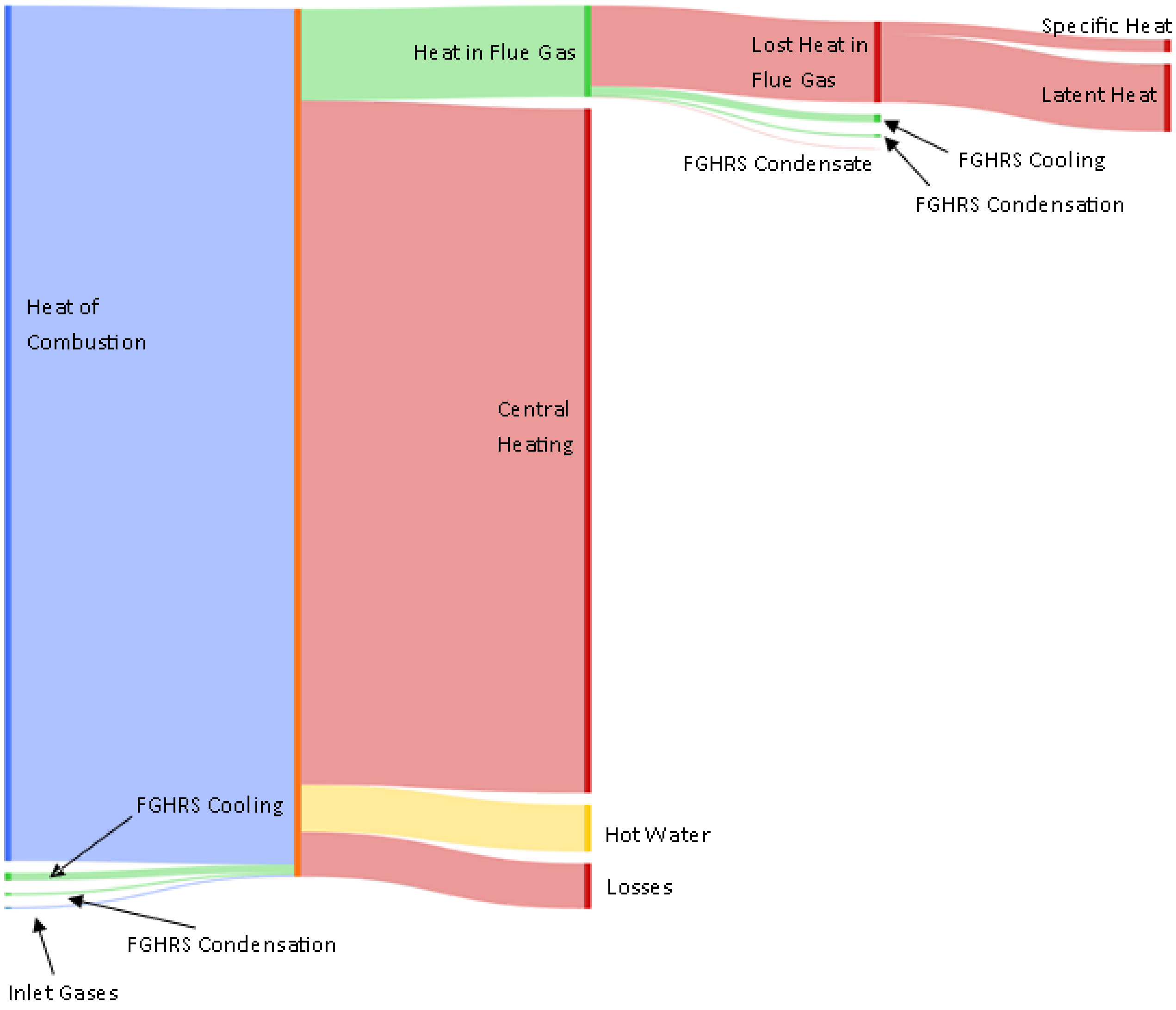


Figure 8: Sankey diagram of the total energy flows (summed over the 24 h experiment run time) for the boiler with external FGHRS, run under a February M tapping test

It is evident from Figure 13 and Figure 14 above that comparatively, the action of the FGHRS is small when compared to the other energy flows into and out of the system. Under optimal conditions, the FGHRS in this system was cooling the flue gas from 68°C to 52°C, a relatively small difference given the low specific heat capacity of the gas (despite the presence of higher humidity). It also condensed approximately 0.5g of water for every litre of natural gas consumed over the course of the experiment, a relatively small condensate flow, which therefore did not recover a significant amount of latent heat for water preheating, despite the large latent heat this recovers.

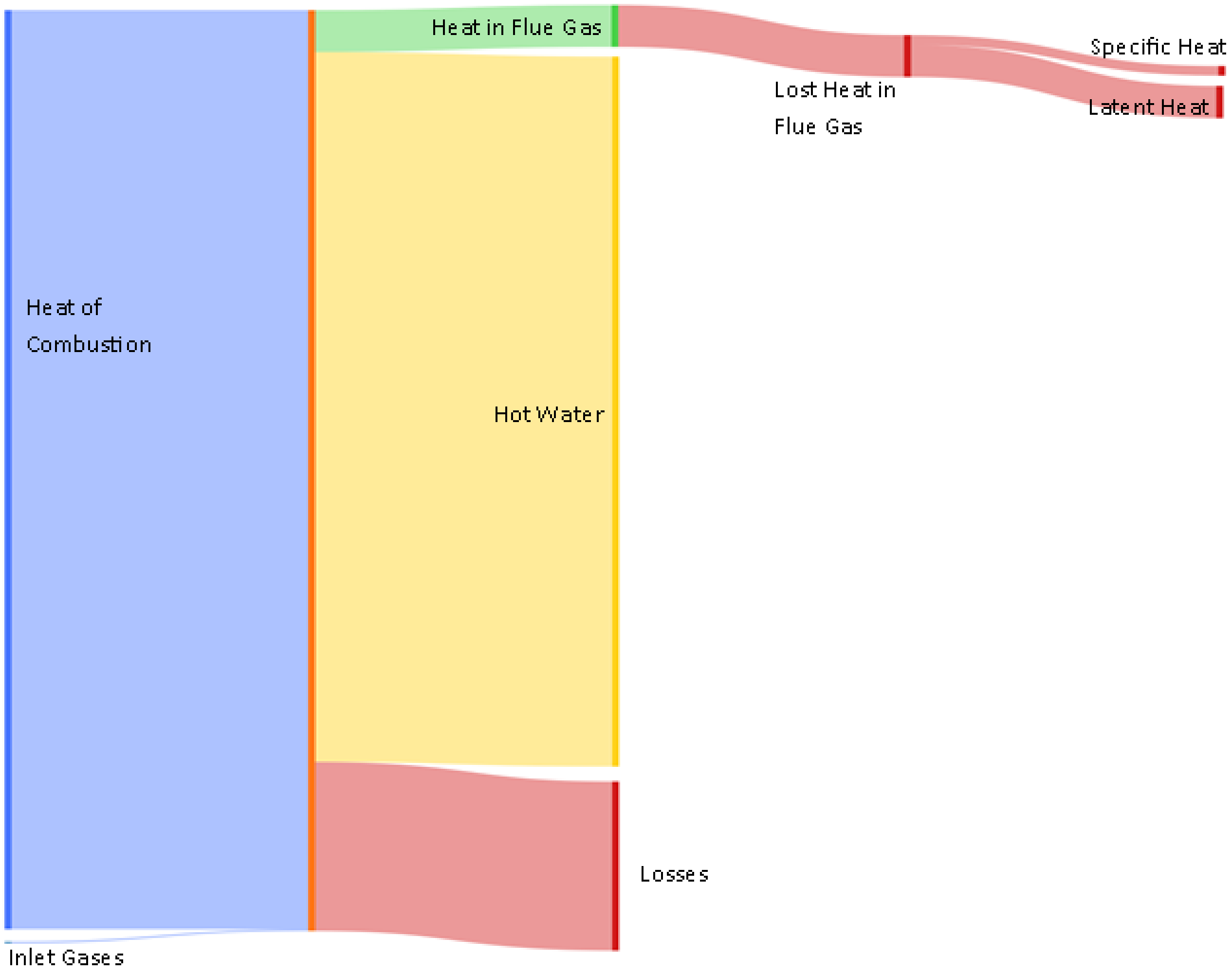


Figure 9: Sankey diagram of the total energy flows (summed over the 24 h experiment run time) for the boiler only, run under a July M tapping test

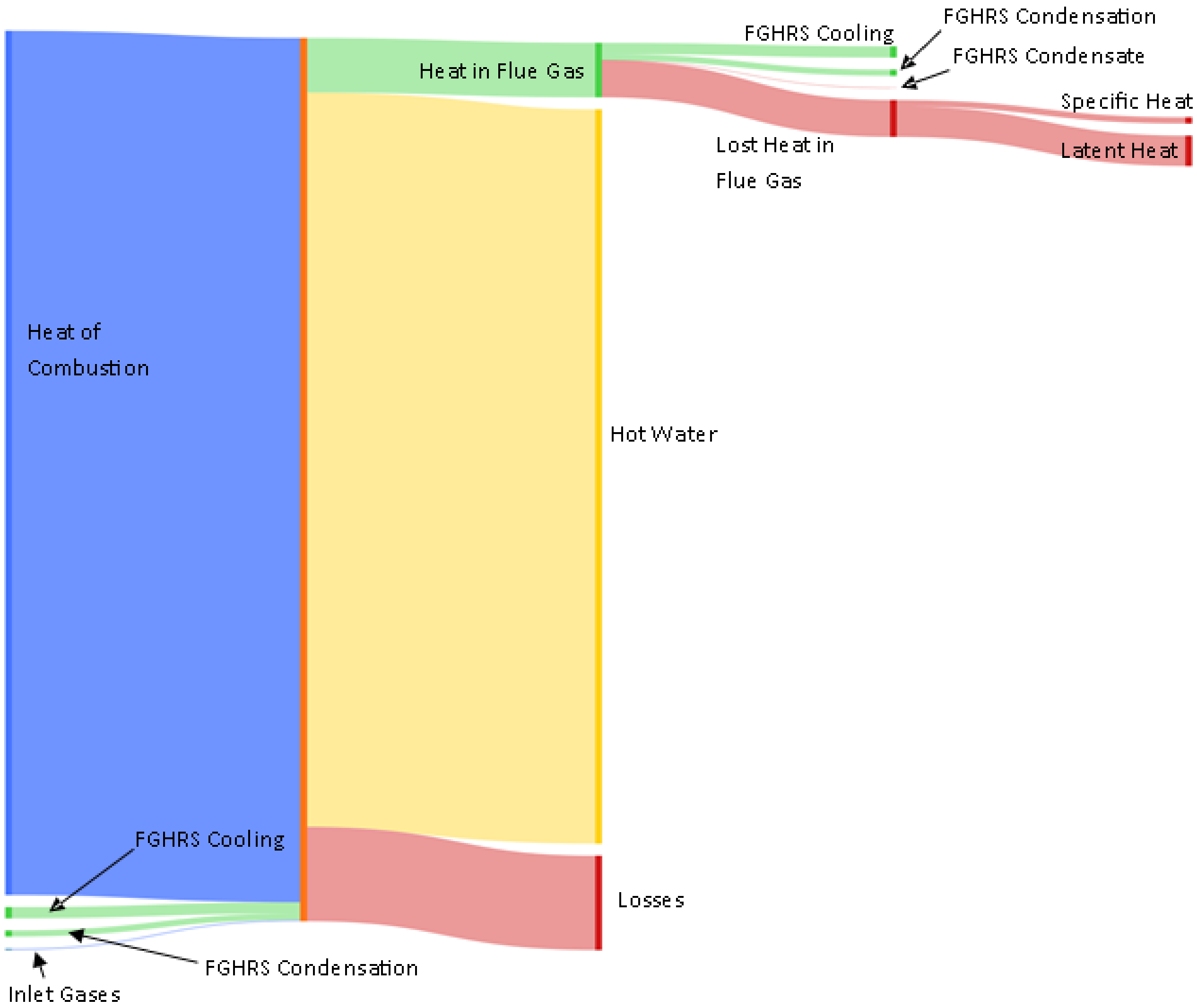


Figure 10: Sankey diagram of the total energy flows (summed over the 24 h experiment run time) for the boiler with external FGHRS, run under a July M tapping test

Much like it was for the winter mode running, the summer mode FGHRS system shows relatively insignificant contributions to the overall energy balance, albeit with a slightly greater proportional share of the total energy input. This is due to a very similar fall in temperature through the FGHRS in summer mode (60 – 40°C) as in winter (68 – 52°C), and a slightly larger (proportionally) condensate flow due to the lower temperature emerging from the FGHRS. The FGHRS also recovers a significant amount more of the available heat in the flue gas, again due to the lower temperature, and therefore lower specific heat and humidity of this flue gas.

5.5.2 DHW Performance change for Boiler alone as heat load increases

This test is slightly off-topic but may have important consequences as to the potential savings available to FGHRS. A one-off test was carried out with the boiler alone to compare the difference in its summer-time performance compared to its performance when heating using the February load profile

Table 11 Effect of Space heating on Boiler DHW efficiency

	Boiler Summer	Boiler February
DHW Heat load profile	M	M
Heating pattern	None	Unimodal
DHW gas use, kWh	7.85	6.94
DHW Efficiency (Gross basis), %	74.6	84.4

This showed the boiler DHW efficiency increased from 74.6% to 84.4%, this is solely due to the fact the boiler burner and heat exchangers are preheated by the space heating load. This represents a gas saving of 11.6% which is very significant. This leads to the question of how much of the saving shown by FHRS technologies is due to the technology and how much is because of the preheating of the boiler? SAP already adjusts the efficiency of the DHW production on a month-by-month basis, with higher efficiencies used during heating season months, but the change recorded here is somewhat larger than the SAP adjustments. This may also impact on the 'additional combi-losses' calculated in SAP. This effect should be more fully investigated both in connection with potential FGHRS savings and also for standard combination boilers to ensure that the effects of preheating the boiler are fully represented in SAP.

5.5.3 EN13203-7 testing

Testing on the storage FGHRS has also been completed on the draft standard EN13203-7.

This requires an EN13203-2 'summer' efficiency determination and also determination of the amount of heat contributed indirectly from the store of the FGHRS.

The method used was the short test method rather than the 24 hour method (see Section 4.2.3). It has been assumed that these methods are equivalent, however, if EN13203-7 were to be adopted then it would be necessary to confirm this.

Tests were done at boiler space heating water temperatures specified, that is a flow water temperature of 43°C and a return water temperature of 37°C giving an average of 40°C, this is to be done whilst the boiler is operating at 30% part load based on Q_n.

Additional testing has also been completed with a flow water temperature of 53°C and a return water temperature of 47°C giving an average of 50°C, this is to allow comparison with the results from the current BRE FGHRS test method, which are done at these temperatures.

Note: the gas CV used in the calculations here is the Gross CV, to maintain consistency across the report and allow comparisons between these tests and the experimental work on the DHLTR. The actual test standard specifies that the Net CV should be used. This means that the efficiencies shown here appear to be lower and gas energy uses would appear to be higher than would normally be expected (when compared to those calculated with net CV), however, consistency with the rest of the report is more important here.

Method Summary

The boiler + FGHRS was tested as described in the draft EN13203-7 standard. The FGHRS is first cooled to 10±1°C. Then allowed to be heated for 30 minutes with the flue gases from a space heating load set up with an average water flow/return temperature of 40°C at part load of 30%, Q_n. The boiler is then switched off, and the system allowed to settle for 1 minute, then water is drawn off at a steady 3L/min until the water temperature is again 10±1°C. During this time the burner stays off.

The first energy draw-off, $Q_{tappedsmall,1}$ is the sum of all energy until 2 L has been drawn off.

The second energy draw-off, $Q_{tappedlarge,1}$ is the sum of all energy until the exit temperature is within 1°C of the inlet temperature.

The test is then repeated but with a heating period of only 15 minutes, this gives $Q_{tappedsmall,2}$ and $Q_{tappedlarge,2}$.

Results for tests done with averaging charging temperature at 40°C

Table 12: Draft EN13203-7 tests – Test 6

Test 6	Time
Pre heat time	30 mins
DHW flow time	15 mins

$Q_{tappedsmall,1}$ =	2.65E-02	kWh	volume=	2.005	L
$Q_{tappedlarge,1}$ =	9.56E-02	kWh	volume=	23.738	L

Table 13: EN13201-7 tests - test 7

Test 5	Time
Pre heat time	15 mins
DHW flow time	15 mins

$Q_{tappedsmall,2}$ =	2.27E-02	kWh	volume=	2.014	L
$Q_{tappedlarge,2}$ =	7.62E-02	kWh	volume=	20.996	L

The table in draft EN13203-7 does not include “S” sized heat load profile so for the purposes of this report it has been extended to include it. This was done by counting up the types of draw-off and allocating them to the correct category. The table of weightings becomes:

Table 14: Draw-off weightings

Load profile	PARAMETER				
	a	b	c	d	Sum of draw-offs
S	6	3	2	0	11

The Table 8 from the draft standard gives the following parameters

Load profile	PARAMETER				
	a	b	c	d	Sum of draw-offs
M	11	2	7	1	21
L	9	4	7	2	22

It will noted that the number of draw-offs is incorrect for both the M and L Load profiles (M should be 23 and L should be 24), also it is believed the distribution of counts within each category are not all correct.

We have corrected them to what we believe they should be in the following table

Table 15: Draw-off weightings

Load profile	PARAMETER				
	a	b	c	d	Sum of draw-offs
S	6	3	2	0	11
M	11	2	9	1	23
L	10	3	9	2	24

$Q_{indirect}$ is calculated using the parameters from the table above.

$$\mathrm{Q}_{indirect} = \mathrm{a} \times Q_{tappedsmall,1} + \mathrm{b} \times Q_{tappedlarge,1} + \mathrm{c} \times Q_{tappedsmall,2} + \mathrm{d} \times Q_{tappedlarge,2} \qquad \textbf{\textit{[13]}}$$

Where a, b, c and d are chosen according to the table and the Load profile used. From which:

Table 16: $Q_{indirect}$ for different load profiles

	$Q_{indirect}$	
S	0.491	kWh
M	0.816	kWh
L	0.908	kWh

EN13203-2 Summer time DHW tests for boiler with FGHRS gave the following data:

Table 17: EN13202-2 summer operation results

	Gas use	Q_{ref}	Q_{DHW}
	kWh/day	kWh/day	kWh/day
S	3.05	2.1	2.13
M	7.19	5.845	5.85
L	13.46	11.655	11.66

From which it is possible to calculate $Q_{gas,S}$ and $Q_{gas,indirect}$ by:

$$Q_{gas,S} = Q_{gas} \text{ x } Q_{ref} / Q_{DHW} \qquad \textbf{[14]}$$

Where $Q_{gas,S}$ is the summer time daily gas usage for this load profile and unit under test (kWh/day)

Q_{gas} is the measured gas energy used to generate the required DHW load profile (kWh/day)

Q_{ref} is the daily reference energy in the DHW load profile (kWh/day)

Q_{DHW} is the measured daily energy in the DHW load profile tested (kWh/day)

And

$$\mathrm{Q}_{gas,indirect} = Q_{gas,S} / Q_{ref} \times Q_{indirect} \qquad \textbf{[15]}$$

	Gas use (kWh/day)	**Qref (kWh/day)**	**QDHW (kWh/day)**	**Qgas,S (kWh/day)**	**Qgas,indirect (kWh/day)**
S	3.05	2.1	2.13	3.016	0.740
M	7.19	5.845	5.85	7.181	1.033
L	13.46	11.655	11.66	13.452	1.082

The average daily gas use, accounting for before summer and winter operation is then calculated as follows:

$$Q_{gas,p} = \left(Q_{gas,S} - Q_{gas,indirect}\right).\frac{D_w}{D_w + D_s} + Q_{gas,s}.\frac{D_w}{D_w + D_s} \; kWh/day \qquad \textbf{[16]}$$

Where D_w = 200 days

And D_s = 165 days

The annual consumption (without the ambient correction term) is

$$Annual\ gas\ use\ =\ Q_{gas,p}\ \times\ 365\ kWh \tag{17}$$

For the Annual fuel consumption as defined in EN13203-2

$$\mathrm{AFC} = 0.6\ x\ (D_W + D_S)\ x\ [Q_{fuel} + Q_{cor}]\ \ \mathrm{kWh} \tag{18}$$

Where

$$Q_{cor}\ =\ -0.23\ \times\ (Q_{fuel}\ +\ Q_{ref})\ \mathrm{kWh} \tag{19}$$

And Q_{fuel} is the gas energy use on a Gross CV basis, kWh, which for the purposes of this report we have assumed is based on $Q_{gas,p}$.

For the data collected above:

Table 18 Results summary draft EN13203-7 at 40 C

	$Q_{gas,p}$ (kWh/day)	Q_{corr} (kWh/day)	Annual gas use (kWh/y)	AFC (kWh/y)
S	2.61	-0.12	953	546
M	6.68	-0.18	2414	1410
L	12.84	-0.28	4694	2756

For the second set of tests the space heating temperature was increased from 40°C to 50°C

Table 19: 13203-7 tests - Test 7

Test 7	Time
Pre heat time	30 mins
DHW flow time	15 mins

$Q_{tappedsmall,1}$ =	4.22E-02	kWh	volume=	2.036	L
$Q_{tappedlarge,1}$ =	1.69E-01	kWh	volume=	31.188	L

Table 20: 13203-7 tests - Test 8

Test 8	Time
Pre heat time	15 mins
DHW flow time	15 mins

DHW On	10:22:00

$Q_{tappedsmall,2}$ =	2.76E-02	kWh	volume=	2.025	L
$Q_{tappedlarge,2}$ =	9.18E-02	kWh	volume=	22.573	L

$Q_{indirect}$ is calculated using the parameters from the table above, equation [13] .

Where a, b, c and d are chosen according to the table and the Load profile used. From which:

Table 21: $Q_{indirec}$t different load profiles

	$Q_{indirect}$	
S	0.815	kWh
M	1.206	kWh
L	1.361	kWh

This shows that increasing the preheat temperature from 40 to 50°C gives an increase of around 50% in the savings due to the store over those achieved at 40°C. This is a significant change and would be important if future tests are to incorporate testing to this standard.

The EN13203-2 Summer time DHW tests gave the following data is the same as above (Table 23)

From which it is possible to calculate $Q_{gas,S}$ and $Q_{gas,indirect}$ by using Equations [*14*] and [*15*]:

Table 22 Indirect gas saving

	Gas use Q_{fuel} (kWh/day)	Q_{ref} (kWh/day)	Q_{DHW} (kWh/day)	$Q_{gas,S}$ (kWh/day)	$\mathbf{Q_{gas,indirect}}$ (kWh/day)
S	3.05	2.1	2.13	3.016	1.171
M	7.19	5.845	5.85	7.181	1.482
L	13.46	11.655	11.66	13.452	1.571

The average daily gas use ($Q_{gas,p}$), accounting for before summer and winter operation is then calculated using equation [*16*]:

The annual consumption (without the ambient correction term) is calculated using equation [*17*]

For the Annual fuel consumption (AFC) as defined in EN13203-2 is calculated using equation [*18*]

For the data collected above:

Table 23 Results summary EN13203-7 50 C tests

	$Q_{gas,p}$ (kWh/day)	Q_{corr} (kWh/day)	Annual use (kWh/y)	AFC (kWh/y)
S	2.37	-0.06	867	506
M	6.45	-0.12	2325	1368
L	12.55	-0.22	4596	2710

The change in predicted (simple) annual use as flue temperature is raised is compared here:

Table 24 Results Comparison - 40 and 50 C tests

	Annual use – tested with 40°C flue T (kWh/y)	Annual use – tested with 50°C flue T (kWh/y)	Difference (kWh/y)
S	953	867	86
M	2414	2325	89
L	4694	4596	98

The annual usage based on the simpler calculation of 365 x $Q_{gas,p}$ shows a small saving in annual gas use when the preheat temperature is raised, however the total DHW gas use values predicted here are higher than predicted by SAP and the experimental work based on the DHLTR tests.

Taking the total saving compared to the plain boiler i.e. the direct plus the indirect gas use savings for FGHRS based on the draft EN13203-7

Table 25 Total gas savings based on EN13203-7 testing

	40°C Flue T				50°C Flue T			
Profile	Direct gas	Indirect gas	indirect +direct	Saving	Direct gas	Indirect gas	indirect +direct	Saving

	40°C Flue T				50°C Flue T			
	saving kWh/day	saving kWh/day	gas saving kWh/day	kWh/month	saving kWh/day	saving kWh/day	gas saving kWh/day	kWh/ month
S	0.33	0.740	1.06	32.25	0.33	1.171	1.49	45.34
M	0.66	1.033	1.69	51.50	0.66	1.482	2.14	65.15
L	0.93	1.082	2.02	61.28	0.93	1.571	2.50	76.14

The gas savings predicted for an average property, with average DHW demand (M profile) and combining these savings as 165 days summer operation and 200 days winter operation gives a gas saving of 448 kWh/year (40°C test) and 537 kWh/year (50°C test). Combining the values with the SAP assumed 122 summer days and 243 winter days give gas savings of 492 kWh/year (40°C test) and 601 kWh/year (50°C test).

Previously, the maximum annual saving was estimated from DHLTR data as 848 kWh/year this was based on 243 days of space heating operation at winter conditions, which is an unlikely use in the UK. If instead we assume the heating season averages the April profile it is estimated (from the DHLTR data) that the saving would be 603 kWh/year. Which would indicate the results calculated from the EN13203-7 method are slightly on the low side, however when using a raised flue temperature compared to the standard, the values appear to match reasonably well. This may indicate potential for using this test standard in the future.

The main problem with using EN13203-7 as a basis for SAP is its draft status and compatibility with previous entries on to the PCDB database. As the EN13203-7 becomes established then it may in the future offer a better route to determining performance of FGHRS and should probably be considered for inclusion in SAP11. Using this method could reduce the testing requirements for manufacturers of boiler/FGHRS packages (since they would need to test for ErP anyway) but may be more awkward to apply to ‘add-on’ manufacturers.

5.6 Discussion

Two types of FGHRS systems have been tested on the DHLTR, with DHW heat load profiles of S, M and L sizes combined with space heating loads of up to nearly 10kW (approximately 7300 kWh/month). This range covers the energy demands in most of properties in the UK.

Both the instantaneous and storage FGHRS systems have shown that significant savings are possible. Gas savings available have been shown to depend on both DHW demand and space heating load. This work has also highlighted the importance of the configuration of the FGHRS and boiler, in particular the presence of a mixing valve can significantly affect the potential for gas savings.

The savings seen for the M DHW heat load profile vary from 12 to 25% of the gas used for DHW for the IFGHRS and 8 to 40% of the gas used for DHW for the SFGHRS. For very small DHW load as typified by the S DHW heat load profile savings of up to 61% were noted, however, this is for a volume of DHW that is well below that normally encountered in SAP calculations.

The comparison of experimental data with the predictions made by SAP are detailed below.

5.7 Comparison with current SAP methodology

Three properties were created under SAP 2012 and these property profiles were also used in the laboratory tests using the Dynamic Heat Loss Test Rig (DHLTR).

Three properties were based on a required heat loss these being 105W/K house, 300W/K house and a 500W/K house.

Kiwa’s SAP spreadsheet was used to develop this data and it was cross checked against the commercially available Stroma SAP, to ensure that results were consistent.

The SAP 2012 uses data from the current PCDB and the data for SFGHRS parameters appear to be those derived by a method proposed by the manufacturer of the SFGHRS and that are currently under (this) investigation. The results below use these SFGHRS parameters in the comparisons

The following data was obtained showing property heat loss rates and energy requirements for DHW:

Table 26: SAP worksheet - 300W/K Property

SAP data 300 W/K property	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	
SAP heat loss rate, W (97m)	3561	3430	3022	2567	1885	1237	725	727	1312	2099	2961	3450	
Space heating requirement, W	3561	3430	3022	2567	1885	0	0	0	0	2099	2961	3450	
Days/month (41m)	31	28	31	30	31	30	31	31	30	31	30	31	
Est hot water usage, L/day (44m)	112.6	108.5	104.4	100.3	96.2	92.1	92.1	96.2	100.3	104.4	108.5	112.6	
Energy content of DHW, kWh/month (45m)	167.0	146.1	150.7	131.4	126.1	108.8	100.8	115.7	117.1	136.5	149.0	161.8	
SAP predicted gas use for different boiler system, kWh/month (219m)													**Yearly Totals**
Base boiler instantaneous	231	203	213	190	186	170	163	180	180	197	210	225	**2349**
Instantaneous FGHRS	188	165	170	149	143	128	119	136	137	154	168	182	**1838**
Base boiler storage	200	175	181	159	154	139	130	147	148	166	179	194	**1971**
Storage FGHRS	32	17	23	13	26	123	116	131	132	18	21	28	**681**

NB: bracketed numbers indicate line in SAP worksheet data is taken from

Table 27: SAP Worksheet - 105W/K property

SAP data 105 W/K property	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	
Space heating requirement, W (based on 97m)	1210	1170	1058	881	680	0	0	0	0	743	992	1201	
Days/month (41m)	31	28	31	30	31	30	31	31	30	31	30	31	
Est hot water usage, L/day (44m)	78.3	75.4	72.6	69.7	66.9	64.0	64.0	66.9	69.7	72.6	75.4	78.3	
Energy content of DHW, kWh/month (45m)	116.1	101.5	104.8	91.3	87.6	75.6	70.1	80.4	81.4	94.8	103.5	112.4	
SAP predicted gas use for different boiler system, kWh/month (219m)													**Yearly Totals**
Base boiler storage	143	125	130	115	112	100	94	106	107	120	129	139	**1420**
Storage FGHRS	20	14	18	15	18	89	84	95	95	20	18	17	**503**

NB: bracketed numbers indicate line in SAP worksheet data is taken from

Table 28: SAP worksheet 500W/K property

SAP data 500W/K property	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	
Space heating requirement, W (based on 97m)	6247	6045	5466	4549	3497	0	0	0	0	3793	5103	6219	
Days/month (41m)	31	28	31	30	31	30	31	31	30	31	30	31	

SAP data 500W/K property	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	
Est hot water usage, L/day (44m)	122.6	118.1	113.7	109.2	104.8	100.3	100.3	104.8	109.2	113.7	118.1	122.6	
Energy content of DHW, kWh/month (45m)	181.8	159.0	164.1	143.1	137.3	118.4	109.8	125.9	127.5	148.5	162.1	176.1	
SAP predicted gas use for different boiler system, kWh/month (219m)													**Yearly Totals**
Base boiler storage	214	188	195	171	165	149	139	158	159	178	192	208	**2117**
Storage FGHRS	40	22	27	13	14	132	124	140	141	17	25	35	**731**

NB: bracketed numbers indicate line in SAP worksheet data is taken from

The house space heating requirement rates (above line 97m in SAP) were then used in conjunction with the polynomials derived from the laboratory work to determine a predicted gas use for the production of DHW for each of the properties based on the experimental work.

Estimated (from lab data) gas use $Q_{gas,DHW}$ is a function of the space heating requirement. Where the function is defined as the polynomials on Figure 11 and Figure 12.

This gas use is for the standard energy draw-off (dependant on load profile) S=2.1kWh/day, M=5.845kWh/day and L=11.655kWh/day

The estimated monthly gas use for DHW can be calculated as

$$Q_{gas,DHW,monthly}=\frac{Requiredenergycontentof DHW formonth(SAPline45m)}{Energy\ required\ for\ tapping\ load\ profile}\times Q_{gas,DHW} \qquad \textbf{[20]}$$

Table 29: 300W/K property storage FGHRS

300 W/K property Storage FGHRS

From polynomial - Estimated gas use for DHW based on SAP heat loss rate (97m)	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Storage FGHRS, M load, kWh/day	4.97	5.02	5.17	5.38	5.77	7.28	7.28	7.28	7.28	5.64	5.20	5.01
Storage FGHRS, L load, kWh/day	11.55	11.61	11.78	11.99	12.33	13.39	13.39	13.39	13.39	12.22	11.81	11.60
Estimated gas based on Energy content of DHW (45m)												

Totals

Storage FGHRS, based on M load, kWh(gas)/month	142	125	133	121	124	135	126	144	146	132	133	139	**1600**
Storage FGHRS, based on L load, kWh(gas)/month	166	145	152	135	133	125	116	133	135	143	151	161	**1695**

Table 30: 300 W/K property instantaneous FGHRS

300 W/K property Instantaneous FGHRS

From polynomial - Estimated gas use for DHW based on SAP heat loss rate (97m)	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	
Instant FGHRS, M load, kWh/day	6.58	6.60	6.67	6.75	6.90	7.47	7.47	7.47	7.47	6.85	6.68	6.60	
Instant FGHRS, L load, kWh/day	12.98	13.01	13.09	13.17	13.28	13.45	13.45	13.45	13.45	13.25	13.10	13.00	
Estimated gas based on Energy content of DHW (45m)													Totals
Instant FGHRS, based on M load, kWh(gas)/month	188	165	172	152	149	139	129	148	150	160	170	183	**1904**
Instant FGHRS, based on L load, kWh(gas)/month	186	163	169	149	144	126	116	134	135	155	167	180	**1824**

Table 31: 500W/K property

500 W/K property

From polynomial - Estimated gas use for DHW based on SAP heat loss rate (97m)	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	
Storage FGHRS, M load, kWh/day	5.54	5.57	5.68	5.87	6.13	7.33	7.33	7.33	7.33	6.06	5.75	5.55	
Storage FGHRS, L load, kWh/day	11.77	11.81	11.93	12.13	12.39	13.43	13.43	13.43	13.43	12.32	12.01	11.78	
Estimated gas based on Energy content of DHW (45m)													Totals
Storage FGHRS, based on M load, kWh(gas)/month	172	152	159	144	144	149	138	158	160	154	160	167	**1856**
Storage FGHRS, based on L load, kWh(gas)/month	184	161	168	149	146	136	126	145	147	157	167	178	**1864**

Table 32: 105W/K property

105 W/K property

From polynomial - Estimated gas use for DHW based on SAP heat loss rate (97m)	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	
Storage FGHRS, M load, kWh/day	4.91	4.95	5.06	5.29	5.62	7.28	7.28	7.28	7.28	5.50	5.14	4.92	
Storage FGHRS, S load, kWh/day	1.61	1.64	1.73	1.89	2.10	3.06	3.06	3.06	3.06	2.03	1.79	1.62	
Estimated gas based on Energy content of DHW (45m)													Totals
Storage FGHRS, based on M load, kWh(gas)/month	98	86	91	83	84	94	87	100	101	89	91	95	**1099**
Storage FGHRS, based on S load, kWh(gas)/month	89	79	86	82	88	110	102	117	118	92	88	87	**1139**

Comparison of the predictions from experimental results with predictions from SAP.

Instantaneous FHGRS gas use for DHW results, only for 300 W/K property:

Table 33: Instantaneous FGHRS lab vs SAP results comparison

	SAP Standard boiler	Current SAP Instantaneous FGHRS	Prediction from DHLTR kWh/year based on	
Property	kWh/year	kWh/year	‘M’ heat load profile	‘L’ heat load profile
300 W/K	2349	1838	1904	1824

Storage FHGRS gas use for DHW results:

Table 34: Storage FGHRS lab vs SAP results comparison

	SAP Standard boiler	Current SAP Storage FGHRS	Prediction from DHLTR data kWh/year based on		
Property	kWh/year	kWh/year	‘S’ heat load profile	‘M’ heat load profile	‘L’ heat load profile
300 W/K	1971	681	-	1600	1695
105 W/K	1420	503	1139	1099	-
500 W/K	2117	731	-	1856	1864

Instantaneous FGHRS comparison summary

Table 35: Instantaneous FGHRS predicted savings comparison

	Predicted gas use compared to standard boiler	
Property	Current SAP predicted, %	DHLTR predicted, %
300 W/K	78.2	79.3

Storage FGHRS comparison summary

Table 36: Storage FGHRS predicted savings comparison

	Predicted gas use compared to standard boiler	
Property	Current SAP predicted, %	DHLTR predicted, %
300 W/K	34.6	83.6
105 W/K	35.4	78.8
500 W/K	34.5	87.9

The comparison tables above show that the data from the DHLTR test work done on the instantaneous boiler fits reasonably well (although not exactly) with the predictions from the current SAP system, whereas the data for the Storage FGHRS shows a very large discrepancy between predictions from the current SAP and the DHLTR test work. It would be expected that SAP would produce gas use values slightly higher than those determined from the laboratory tests since the laboratory tests measure DHW output at the boiler exit and therefore do not include losses attributed to combi-loss, such as lukewarm water losses.

The major difference between these calculations is that the instantaneous boiler has been calculated solely from standard summer mode DHW test data (EN13203-2) and using the appropriate additional combi loss calculations in SAP 2012. The storage FGHRS calculation relies on data obtained from additional experimental work and calculations under Appendix G of SAP. The current SAP predictions appear to overestimate the savings that are likely to be achievable from the use of storage FGHRS technologies.

The above results have been calculated using the values current available in PCDB/SAP, for the Storage FGHRS device tested, there are 2 sets of data that have been used in SAP. The original set calculated by BRE using their original methodology and the current set which has had input from the manufacturer, resulting in a different set of parameters in the PCDB data file in each case.

For comparison purposes the original data calculated from the original BRE methodology for the SFGHRS under test was put into SAP and the gas use for DHW purposes was recalculated on this basis.

For the 300 W/K property the predicted gas use was 845 kWh/year, this is somewhat larger than the current SAP prediction but still significantly less than the experimental data is showing.

As a result of this data analysis it was decided that none of the current methodologies used to estimate the savings due to storage FGHRS give acceptable results. It was decided to work on a detailed analysis of the current methods and models used to characterise storage FGHRS within SAP and to verify the thermodynamic processes contributing to the potential savings obtainable from FGHRS, with the objective of producing a methodology that provided more realistic results but maintained compatibility with SAP.

Please note Kiwa have complete confidence in the results presented in Section 5 of this report, however, caution should be undertaken if they are extrapolated beyond the stated test conditions or to operating regimes different from those used in this test programme.

5.8 Other factors affecting the performance of FGHRS

Any devices or control systems that reduce the temperature of the flue gases leaving the boiler or change the duration the boiler operates for, will impact the operation of FGHRS. We have not had to opportunity to extend test work to cover any of the many possible devices or test conditions that could have this sort of effect. It is clear that operating the boiler at low temperatures either directly or as a result of temperature compensation, will reduce the energy available to the FGHRS. The test work here has been done with a limited number of temperature conditions. The average Flow/return temperatures for the DHW production period are shown below.

	300W/K	105W/K	500W/K
Summer	18.8	19.0	19.1
April	42.1	43.6	40.8
Feb	53.4	54.9	52.0
Winter	55.7	57.2	54.7

The laboratory results show reduced gains in efficiency, at lower average temperatures. So this could indicate that systems running at lower temperature should show lower savings due to FGHRS. This cannot be dealt with in the methodology envisaged here and must form part of a modification of the SAP procedure.

The laboratory results show a 3-4% point reduction in gas savings when the average boiler space heating water temperature drops by 10° C. This could form the basis of a correction for low temperature systems or compensating controls. The reduction in savings for compensating controls would have to be varied across the year.

6. Scoping of alternative method

6.1 Rationale

The laboratory testing (see Section 5 above) of the different types of FGHRS has shown that whilst instantaneous FGHRS appear to be well represented under SAP, storage FGHRS are not. SAP currently predicts much greater savings from storage FGHRS than have been shown to be achieved in practical testing. A review of both current the BRE method and alternative suggestions (see Section 4) has shown that all current methodologies have problems in both implementation and logic.

It was decided that any new method should be based on the existing testing methodology, since alternatives based on EN13203-7 are not feasible until the standard is finalised and also to maintain compatibility with existing data sets. See Section 6.2.

The methodology must be robust mathematically and in its representation of the physics and engineering of the device under test. It must also be transparent, so that it can be understood by the engineer/PCDB assessor using it. The methodology is discussed in detail in Section 6.3 and the main areas of change are documented in section 6.3.6.

6.2 Testing requirements

There are two main choices with regard to testing regimes, these are to maintain the current methodology or to use the draft EN13203-7. The former has the advantage that some compatibility is maintained with previous test results and is a procedure that test labs are familiar with. However, it is considered that it needs to be tightened and more specific in certain areas. EN13203-7 has potential and if it is adopted then manufacturers would have to test to it anyway, but at present it is in draft and may be subject to change. Based on our laboratory tests, it also seems to under-predict the potential savings of FGHRS technology.

As EN13203-7 is still liable to change, it has been decided to remain with the current testing methodology, with the following changes (the full specification is presented in Annex C)

Significant changes are:

- Ambient temperature maintained more accurately at 20±2°C.
- Tighter control of flow and return temperatures in charging tests
- Data logging rate increased to 1 second interval for discharge tests.
- Charging test begins with SFGHRS store at cold water inlet temperature.
- One minute fixed period between end of charging test and start of subsequent test.
- Burner off during discharge test.
- FGHRS must be tested on a compatible boiler.

There is a requirement to define what constitutes a storage FGHRS, and it is suggested that this could be based upon the liquid content of the device. We would suggest wording similar to the following:

For a FGHRS to be classified as a storage device and hence be required to be entered into SAP via Appendix G: the minimum DHW volume should be greater than 2 Litres or if condensate is stored this should be greater than 2 L to qualify. Devices featuring solid materials to retain heat do not count unless they meet the liquid volume requirements.

The reasoning behind this is as follows: The smallest draw-off in the 'M' load profile is 150Wh if we assume a DHW temperature rise of 50 K then this energy content equates to about 2.6 Litres of water, any store should be able to provide a significant proportion (if not all) of this volume as preheated water

6.3 Development of New Methodology for predicting performance of SFGHRS in SAP

6.3.1 Energy saving in FGHRS models

There are 3 main areas in which FGHRS can save energy when represented in SAP.

These are the

- Direct saving, as identified by the change in efficiency between the test of the boiler alone under EN13203-2 and the test of boiler plus FGHRS.
- Indirect saving, energy recovered from any store preheated by the space heating function of the boiler
- Change in 'additional combi loss' parameter - correction of SAP combi loss parameter (SAP Tables 3a, b and c) to account for energy savings in DHW distribution pipework (lukewarm water loss reduction) due to use of FGHRS.

6.3.2 Direct savings

The direct savings due to the use of FGHRS technology are based on the EN13203-2 tests done on the plain boiler and the boiler with the FGHRS. These tests represent the summertime improvement in the performance provided by an FGHRS, and the reduction in wasted water at the boiler DHW exit.

The EN13203-2 test allows the efficiency to be determined both without and with wasted water. With the FGHRS in use it is expected to see a reduction in wasted water percentage. Although with modern combination boilers wasted water is often a very small amount.

If η_{Boiler} and η_{FGHRS} are the DHW efficiency of the boiler alone and the boiler with the FGHRS respectively (including any wasted water) as determined by EN13203-2 tests, then for a hot water demand ($Q_{DHW,demand}$) of the saving in gas use ($Q_{gas,saved}$) in summer mode (i.e. no space heating) will be:

$$Q_{gas,saved} = \frac{Q_{DHW,\,demand}}{\eta_{boiler}} - \frac{Q_{DHW,\,demand}}{\eta_{FGHRS}} \qquad \textbf{[21]}$$

If this is converted back to an equivalent DHW energy requirement then the DHW energy demand will be reduced (QDHW,demand,saved) due to the increase in boiler efficiency, however the boiler efficiency used here depends on how the appliance is handled within SAP. For appliances with integral FGHRS and DHW data determined by an EN13203-2 test and recorded in PCDB as the efficiency with the FGHRS, then the efficiency used should be that of the combined boiler and FGHRS system. ηFGHRS :

$$Q_{DHW,\,demand,saved} = Q_{DHW,\,demand}.\left(\frac{1}{\eta_{boiler}} - \frac{1}{\eta_{FGHRS}}\right).\eta_{FGHRS} \tag{22}$$

For add on type products the gas use for DHW is determined on the basis of the boiler only, and a correction added on later for the FGHRS, so in this case the DHW saving is:

$$Q_{DHW,\,demand,saved} = Q_{DHW,\,demand}.\left(\frac{1}{\eta_{boiler}} - \frac{1}{\eta_{FGHRS}}\right).\eta_{boiler} \tag{23}$$

Simplifying for integral products,

$$Q_{DHW,\,demand,saved} = Q_{DHW,\,demand}.\left(\frac{\eta_{FGHRS}}{\eta_{boiler}} - 1\right) \tag{24}$$

And for add-on products:

$$Q_{DHW,\,demand,saved} = Q_{DHW,\,demand}.\left(1 - \frac{\eta_{boiler}}{\eta_{FGHRS}}\right) \tag{25}$$

However, with storage FGHRS, part of the heat demand is met from the store and so $Q_{DHW,demand}$ must be reduced by this amount, so $Q_{DHW,demand,saved}$ for integral type products (assuming they have some storage) becomes

$$Q_{DHW,\,demand,saved} = \left(Q_{DHW,\,demand} - Q_{indirect}\right).\left(\frac{\eta_{FGHRS}}{\eta_{boiler}} - 1\right) \tag{26}$$

And for add-on type products it becomes:

$$Q_{DHW,\,demand,saved} = \left(Q_{DHW,\,demand} - Q_{indirect}\right).\left(1 - \frac{\eta_{boiler}}{\eta_{FGHRS}}\right) \tag{27}$$

Where $Q_{indirect}$, the saving due to the accumulation of energy in the FGHRS store is as determined by EN13203-7 (Section 5.5.3) or as determined below in Section 6.3.3

If there is a keep hot facility then the efficiencies used should be the ones excluding the wasted water, instead of those including it.

This is called the Direct saving in the spreadsheet model. This saving includes any reduction in the amount of wasted water at the boiler exit from using the FGHRS compared to the boiler alone.

6.3.3 Development of model to represent indirect savings

6.3.3.1 Analysis of Energy flows around a FGHRS

Calculation of the contribution of FGHRS to the performance of a building within SAP is achieved by modelling heat flows using some measured parameters. Overall, the heat flows into an FGHRS must balance with those out of an FGHRS taking into account the effect of heat held within it.

A model of the energy flows around a FGHRS can be represented as the figure below:

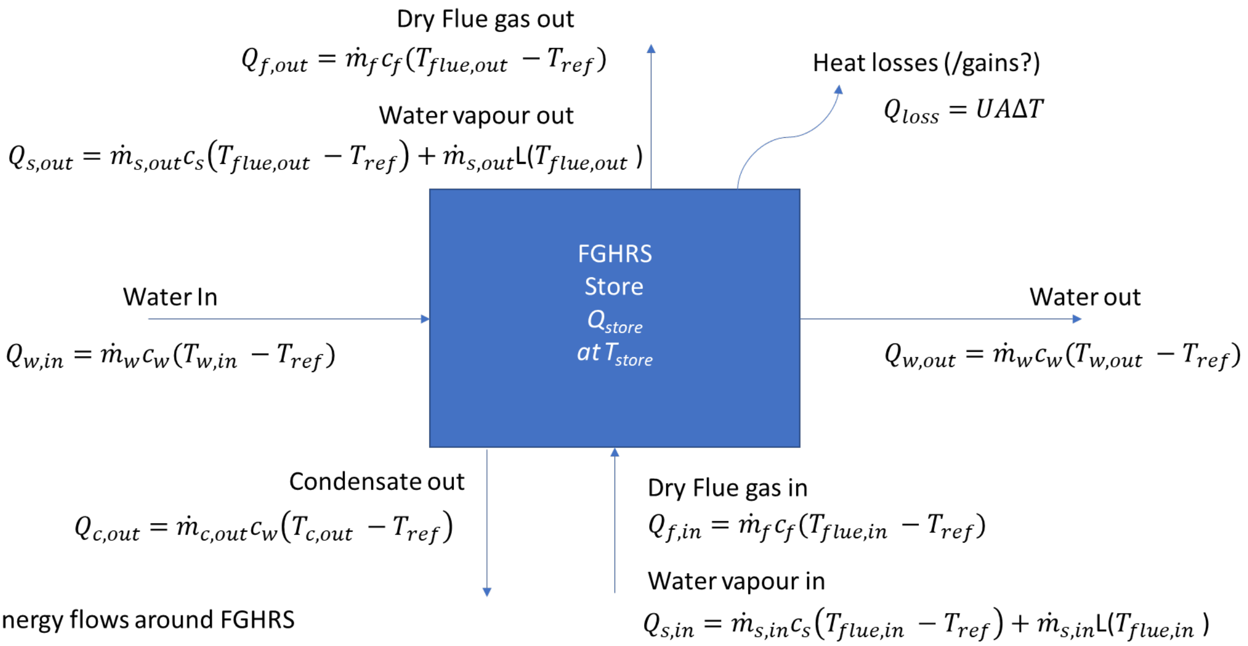


Figure 11 Energy flows around a FGHRS

The notations for all the parameters in this methodology description are provided in Appendix A

The amount of heat energy in the store at any point is determined by its temperature, materials of construction and liquid (eg water/condensate) content. Any changes in the store energy must be completely balanced by heat flows that have entered and left the store.

The objective is to estimate the overall energy balance over individual days of operation and from these to estimate the contribution to the overall energy flows calculated in the SAP dwelling model.

The change in energy in the store over a small time interval (*Δt*) is the sum of all the heat flow rates during that interval multiplied by the length of the interval. The rate of change of heat content of the store can be defined as:

$$\frac{\Delta Q_{store}}{\Delta t} = \dot{Q}_{f,in} + \dot{Q}_{s,in} + \dot{Q}_{w,in} - \dot{Q}_{f,out} - \dot{Q}_{s,out} - \dot{Q}_{w,out} - \dot{Q}_{c,out} - \dot{Q}_{loss} \qquad \textbf{[28]}$$

For this model to be used values for each of the parameters is required. Depending on the conditions and system operation the values can vary significantly and at times be zero, although this is seldom the case for Q_{loss} which is zero only when the system has been inactive for long enough to reach ambient temperature throughout.

The current set of laboratory tests used to characterise storage FGHRS, provide only partial information to populate all the equations in the model above. In particular, the mass flow rate of flue gas and the mass flow rate of the condensate are not known. These could be estimated as during the charging tests when the boiler is firing the carbon dioxide concentration should be recorded and from this it is possible to estimate the flue gas mass flow rate. It is also possible to estimate the water vapour content of the flue gas by assuming it is saturated (as it should be if using natural gas and the flue temperature is less than approximately 57°C). This however means the analysis of the data is somewhat complex.

Previous models [BRE, Methods 1 and 2] (described above in Section 44) have used a simplified method of analysing this data considering the change in energy content as a sum of charging (heating up water held in the FGHRS), discharging (removal of heat from the FGHRS by outflow of DHW) and cooling (as result of heat losses from the FGHRS) processes which match with the laboratory test regimes.

$$\frac{\Delta Q_{store}}{\Delta t} = Q_{charging} - Q_{discharging} - Q_{cooling} \qquad \textbf{[29]}$$

For this investigation an objective is to check and, if necessary, change the model used to estimate the heat saved by operation of a FGHRS. Constraints include:

- the need to avoid modifying SAP so the same parameters need to be provided by any new model as those currently used in SAP
- the need to avoid additional testing for products already included in the PCDB

To apply the more detailed model (summarised in equation [*28*]) would require more extensive data sets. This would conflict with these constraints and re-tests would be needed for products already included in the PCDB. So, for this investigation it has been necessary to use equation [*29*] as the basis of the model. However, the energy balance from equation [*28*] must still be borne in mind during this analysis as it provides a much fuller picture of the physical processes contributing to the performance of FGHRS.

6.3.3.2 Interpretation of data from current and future test protocol

To obtain the process rates used in the simplified model it is necessary to process the data from laboratory tests. There are three tests that produce temperature / time profile data (Cooling, Charging and Discharging) from which overall heat transfer coefficients are derived for each process. If these processes all operated independently this would be fairly straightforward. In fact, there are times when processes operate simultaneously which seems to give rise to complications with regards to the charging overall heat transfer rate as mentioned in the relevant section below.

Cooling test

The analysis of the cooling test data is the same using either equation as $Q_{cooling} \equiv Q_{loss}$.

By assuming the store is well mixed, and the store temperature is representative of the FGHRS as a whole and the system loses heat by simple convective heat transfer. This assumption seems reasonable with regards to the work in this project as the device data seems to show the array of temperature sensors in the store show consistent temperatures. However, detailed measurements in the FGHRS during all operating states would be needed to determine whether it is universally applicable or if under some situations an element of plug flow is present, and this was beyond the scope of the project.

During the cooling test equation [29] simplifies to

$$\frac{\Delta Q_{store}}{\Delta t} = -Q_{loss} \tag{30}$$

Where

$$Q_{loss} = U.A.\Delta T \tag{31}$$

U is overall heat transfer coefficient

A is heat transfer area

ΔT is the temperature difference between the store average temperature (T_{store}) and the surrounding environment temperature (T_{amb}):

$$\Delta T = T_{store} - T_{amb} \tag{32}$$

So

$$Q_{loss} = \mathrm{U.A.}(T_{store} - T_{amb}) \tag{33}$$

Heat loss is from the heat contained in the store (Q_{store}) which is also a function of T_{store}. The total energy in the store is:

$$Q_{store} = m_{store} c_{store} \left(T_{store} - T_{ref}\right) \tag{34}$$

Where m_{store} is total mass of store and its water content and c_{store} is the weighted specific heat capacity of the store and its contents. The mass of liquid in the FGHRS is assumed constant, with any evaporation of condensate being replenished by condensation from the flue gases and any over production of condensate drained away back through the boiler.

As the average temperature of the store changes (ΔT_{store}) the total energy in the store (ΔQ_{store}) will change as time goes from t to t+Δt, as follows:

$$Q_{store,t} - Q_{store,t+\Delta t} = m_{store}c_{store}(T_{store,t} - T_{ref}) - m_{store}c_{store}(T_{store,t+\Delta t} - T_{ref}) \quad \textbf{[35]}$$

hence

$$Q_{store,t} - Q_{store,t+\Delta t} = m_{store}c_{store}(T_{store,t} - T_{store,t+\Delta t}) \quad \textbf{[36]}$$

Let

$$\Delta Q_{store} = Q_{store,t} - Q_{store,t+\Delta t} \quad \textbf{[37]}$$

And

$$\Delta T_{store} = T_{store,t} - T_{store,t+\Delta t} \quad \textbf{[38]}$$

Then

$$\Delta Q_{store} = m_{store}c_{store}\Delta T_{store} \quad \textbf{[39]}$$

Substitute Equations [*33*] and [*39*] into Equation [*30*] to give:

$$\frac{m_{store}c_{store}\Delta T_{store}}{\Delta t} = U.A.(T_{store} - T_{amb}) \quad \textbf{[40]}$$

Let

$$U_c = \mathrm{U.A} \quad \textbf{[41]}$$

and

$$K = m_{store}c_{store} \quad \textbf{[42]}$$

NOTE: Whilst the use of overall mass of the store and the average heat transfer coefficient simplify the derivations presented here in the spreadsheet model K is derived from the masses of the water and the metal of the store and their individual heat capacities.

Substitute and rearrange to give:

$$\frac{\Delta T_{store}}{\Delta t} = \frac{U_c}{K}(T_{store} - T_{amb}) \qquad \textbf{[43]}$$

Which in differential form is:

$$\frac{dT_{store}}{dt} = \frac{U_c}{K}(T_{store} - T_{amb}) \qquad \textbf{[44]}$$

Which can be explicitly solved (see Appendix B) to give:

$$T_{store} = (T_{init} - T_{amb}).e^{\left(\frac{U_c.t}{K}\right)} + T_{amb} \qquad \textbf{[45]}$$

Where

T_{init} is the store temperature at the start of cooling test

Cooling test data can then be fitted to this equation, to provide the value of the constant U_c. K is derived from the physical information on the device (masses of metal and water and their specific heat capacities). T_{init} is the temperature of the store at the start of the cooling period.

Charging test

During the charging test, only two processes are active, cooling and charging. So, Equation [*29*] becomes

$$\frac{\Delta Q_{store}}{\Delta t} = Q_{charging} - Q_{loss} \qquad \textbf{[46]}$$

Where

$$Q_{charging} = Q_{f,in} + Q_{s,in} - Q_{f,out} - Q_{s,out} - Q_{c,out} \qquad \textbf{[47]}$$

And from equations [*30*], [*33*] and [*41*]

$$Q_{loss} = U_c(T_{store} - T_{amb}) \qquad \textbf{[48]}$$

Treating charging as an overall process equation [*47*] can be simplified to

$$Q_{charging} = U_{ch}\left(T_{flue} - T_{store}\right) \qquad \textbf{[49]}$$

Where

T_{flue} is the average flue temperature across the FGHRS

U_{ch} is the overall heat transfer coefficient for the charging process

Substituting equations [*39*], [*42*], [*48*], [*49*] and into equation [*46*]

$$K.\frac{\Delta T_{store}}{\Delta t} = U_{ch}(T_{flue} - T_{store}) - U_c(T_{store} - T_{amb}) \quad \textbf{[50]}$$

Rearranging and turning to differential form:

$$\frac{dT_{store}}{dt} = \frac{U_{ch}}{K}(T_{flue} - T_{store}) - \frac{U_c}{K}(T_{store} - T_{amb}) \quad \textbf{[51]}$$

This can be explicitly solved (see Appendix B) and setting initial conditions

$$T_{store} = \frac{U_{ch}T_{flue} + U_cT_{amb} - \left(U_{ch}(T_{flue} - T_{init}) - U_c(T_{init} - T_{amb})\right)e^{\left(\frac{(U_{ch}+U_c)t}{K}\right)}}{U_{ch} + U_c} \quad \textbf{[52]}$$

Where: T_{init} = initial store temperature at the start of the charging test.

Charging test data can then be fitted to this equation, using the value for U_c derived from the previous analysis of the cooling data, to provide the value of the constant U_{ch}.

Discharging test

The existing test protocol for the discharge test is ambiguous, in that it does not specifically state whether the boiler should be reheating the water during this test. Most manufacturers appear to have conducted this test with the boiler reheating. However, in section 6.1.3 of the BRE FGHRS document it only considers cooling and discharge factors, not charging.

To fit existing data, it will be necessary to allow for recharging due the boiler firing, the analysis presented here does so. If there is no firing, it is expected that the recharging parameter should be zero.

If we consider all processes happening simultaneously then equation [*28*] applies:

$$\frac{\Delta Q_{store}}{\Delta t} = Q_{f,in} + Q_{s,in} + Q_{w,in} - Q_{f,out} - Q_{s,out} - Q_{w,out} - Q_{c,out} - Q_{loss} \quad \textbf{[28]}$$

In the simplified method this is reduced to equation [*29*]:

$$\frac{\Delta Q_{store}}{\Delta t} = Q_{charging} - Q_{discharging} - Q_{cooling} \quad \textbf{[29]}$$

Where $Q_{cooling}$ and $Q_{charging}$ are defined in equations [*48*] and [*49*] above and:

$$Q_{discharging} = U_{dis}(T_{store} - T_{cold}) \qquad \textbf{[53]}$$

During the discharging test, three processes are active, cooling, charging and discharging. Substituting equations [*48*], [*49*] and [*53*] into equation [*29*] gives:

$$m_{store}c_{store}\frac{\Delta T_{store}}{\Delta t} = U_{ch2}\left(T_{flue} - T_{store}\right) - U_c(T_{store} - T_{amb}) - U_{dis}(T_{store} - T_{cold}) \qquad \textbf{[54]}$$

The discharging tests which have been recorded with the boiler enabled will give a different overall heat transfer for charging (called U_{ch2} here) than that produced by the charging tests.

Substituting from equation [*42*] into equation [*54*] and rearranging to give:

$$\frac{\Delta T_{store}}{\Delta t} = \frac{U_{ch2}}{K}\left(T_{flue} - T_{store}\right) - \frac{U_c}{K}(T_{store} - T_{amb}) - \frac{U_{dis}}{K}(T_{store} - T_{cold}) \qquad \textbf{[55]}$$

Changing to differential form:

$$\frac{dT_{store}}{dt} = \frac{U_{ch2}}{K}\left(T_{flue} - T_{store}\right) - \frac{U_c}{K}(T_{store} - T_{amb}) - \frac{U_{dis}}{K}(T_{store} - T_{cold}) \qquad \textbf{[56]}$$

Followed by integration (see Appendix B) gives

$$\textbf{[57]}$$

$$T_{store} = \frac{\left(U_{ch2}T_f + U_{dis}T_c + U_cT_{amb}\right) - \left(U_{ch2}\left(T_f - T_{int}\right) - U_{dis}(T_{init} + T_c) - U_c(T_{init} + T_{amb})\right)e^{-\frac{(U_{ch2}+U_{dis}+U_c)}{K}t}}{(U_{ch2} + U_{dis} + U_c)}$$

Discharging test data can then be fitted to this equation using the constant U_c that from the previous analysis of the cooling data. U_{ch2} and U_{dis} are determined by the best fit for the supplied data.

Effectively, this means that the charging heat transfer coefficient is different for the charging and the discharging tests. This does not appear to make good engineering sense. However, referring back to equation [*28*] then it can be seen the heat transfer from the flue gases is proportional to the both the flow rate and the temperature difference. The current analysis only accounts for the temperature difference. When the boiler is producing DHW at 6 L/min it is likely to be operating between 50% to full output (depending on the water temperature coming from the FGHRS), this means the flue gas flow rate is likely to be considerably higher in this test, than in the charging test, when the boiler is operated at 30% load.

A more detailed analysis of the data using equation [*28*] would be beneficial but not all the factors are available from the tests and therefore several parameters would need to be estimated. This exercise has not been undertaken in this investigation.

6.3.3.3 Simulating the indirect energy saving performance of the FGHRS on a daily basis

Both the BRE and method 1 have used the simplified model equation [*29*] above to determine the change in the energy content of the store over a single day's operation:

$$\frac{\Delta Q_{store}}{\Delta t} = Q_{charging} - Q_{discharging} - Q_{loss} \qquad \textbf{[29]}$$

Which when expanded (substituting from equations [*48*], [*49*] and [*53*])gives:

$$\frac{\Delta Q_{store}}{\Delta t} = U_{ch}\left(T_{flue} - T_{store}\right) - U_{dis}(T_{store} - T_{cold}) - U_c(T_{store} - T_{amb}) \qquad \textbf{[58]}$$

From the experimental test data U_{ch}, U_{dis} and U_c have been determined, a second charging heat transfer coefficient (U_{ch2}) may have also been determined during the discharging test. So, the equation for store energy change becomes:

$$\begin{aligned}\frac{\Delta Q_{store}}{\Delta t} = {} & U_{ch}\left(T_{flue} - T_{store}\right) + U_{ch2}\left(T_{flue} - T_{store}\right) - U_{dis}(T_{store} - T_{cold}) \\ & - U_c(T_{store} - T_{amb})\end{aligned} \qquad \textbf{[59]}$$

This analysis relies on the assumption that the store is well mixed and the store temperature at the exit is the same as in the bulk. Large external stores may need to be handled differently, if the average store temperature as measured in the test (with many sensors) is not representative of the conditions within the store or at its exit.

During any 24 hour period there will be different times when each of the components changing the energy content of the store will take effect.

$Q_{cooling}$ will be in effect at all times during the day:

$$\frac{\Delta Q_{store}}{\Delta t} = \left.\langle -U_c(T_{store} - T_{amb})\rangle\right|_{\text{t=0 to 24 hours}} \qquad \textbf{[60]}$$

$Q_{charging}$ will be in effect at times when the boiler is providing space heating, and at times when the boiler is firing during domestic hot water draw off.

- for t when space heating is on

$$\frac{\Delta Q_{store}}{\Delta t} = \langle U_{ch}\left(T_{flue} - T_{store}\right)\rangle\Big|_{SH,on} \tag{61}$$

- for t when DHW is being drawn and boiler is on, when U_{ch2} is defined

$$\frac{\Delta Q_{store}}{\Delta t} = \langle U_{ch2}\left(T_{flue} - T_{store}\right)\rangle\Big|_{DHW,on} \tag{62}$$

- for t when DHW is being drawn and boiler is on, when U_{ch2} is Not defined

$$\frac{\Delta Q_{store}}{\Delta t} = \langle M.\,U_{ch}\left(T_{flue} - T_{store}\right)\rangle\Big|_{DHW,on} \tag{63}$$

Where M is a multiplier defined as the ratio of boiler maximum output / output in charging test to allow for the increased firing rate of the boiler during DHW production.

$Q_{discharge}$ will be in effect at times when DHW is being drawn off

- for t when discharging DHW

$$\frac{\Delta Q_{store}}{\Delta t} = \langle U_{dis}(T_{store} - T_{cold})\rangle|_{DHW,on} \tag{64}$$

It should be noted that the energy change in discharging the store should be equal to the energy gained by the water flowing through it. The flow rate and inlet temperatures are known and if we assume the store is well mixed then the outlet temperature is equal to the store temperature.

So, energy gained by DHW passing through the store, over time interval Δt is

$$\Delta Q_{DHW} = \dot{m}_{DHW} c_w (T_{store} - T_{cold})\Delta t \tag{65}$$

However, in the daily simulation model the heat gained by water passing through the store is determined by equation [*64]*.

The change in energy of the store (and hence its temperature) is still determined by use of the equations and parameters derived from the discharge test.

The initial conditions are set by assuming a start temperature for the store. The energy in the store is calculated based on a reference temperature (assumed to be 0°C).

For each time step throughout the simulated day the change in energy is calculated based on the equation, if U_{ch2} is defined:

$$\Delta Q_{store} = \left(\begin{array}{c} \left[U_{ch}\left(T_{flue} - T_{store}\right)\Big|_{SH,on} + U_{ch2}\left(T_{flue} - T_{store}\right)\Big|_{DHW,on}\right]_{boiler\ charging} \\ -\left[U_{dis}\left(T_{store} - T_{cold}\right)\right]_{DHW\ discharging} - \left[U_{c}\left(T_{store} - T_{amb}\right)\right]_{all\ time} \end{array}\right)\Delta t \qquad \textbf{[66]}$$

If U_{ch2} is not defined:

$$\Delta Q_{store} = \left(\begin{array}{c} \left[U_{ch}\left(T_{flue} - T_{store}\right)\Big|_{SH,on} + M.U_{ch}\left(T_{flue} - T_{store}\right)\Big|_{DHW,on}\right]_{boiler\ charging} \\ -\left[U_{dis}\left(T_{store} - T_{cold}\right)\right]_{DHW\ discharging} - \left[U_{c}\left(T_{store} - T_{amb}\right)\right]_{all\ time} \end{array}\right)\Delta t \qquad \textbf{[67]}$$

Determining when boiler is firing

The boiler will fire in two circumstances: when there is a space heating demand or when there is a DHW demand.

Space heating

The daily model is integrated into a monthly use model, in this the series of space heating demands embedded in SAP2012 have been used. These are:

0, 200, 1000, 2000, 4000 and 20000 kWh/month

The duration that a boiler must fire to satisfy these demands will vary depending on the size of boiler and its minimum and its maximum space heating outputs.

It has been assumed that space heating will be setup using a bimodal heating pattern, that is, it will on in the morning from 0700 to 0900 and from 1600 to 2300 in the evening. [SAP 2012 Table 9].

It is also assumed that the boiler will operate at its minimum output for as long as possible in this mode. A further assumption is that the boiler heat output rate during the charging test (which is supposed to be at 30% input, in previous versions, now recommended to be 30% output) represents the minimum operating point of the boiler. It is recognised that this may not be the case with some modern gas fired boilers, which are able to modulate to lower output rates, but the assumption is appropriate for this model and these aspects taken together would show FGHRS in an optimal manner. In practice most boilers would operate at full power until temperatures close to the desired flow temperature are reached, before starting to modulate and finally turn off. This would tend to concentrate heating output in the early parts of each bimodal period, or the morning of the unimodal period. To model this would require a standard property simulation built into the FGHRS methodology which would add considerably to its complexity and also lead to much discussion as to what sort of property or properties should be represented.

The time required to meet the demand is:

$$t_{heat,on} = \frac{Q_{demand,month}}{\dot{Q}_{boiler,output} \times N_d} \times 3600 \qquad \textbf{[68]}$$

Where

$Q_{demand,month}$ is desired monthly required in kWh (= heat output from boiler)

$\dot{Q}_{boiler,output}$ is boiler output at 30% load in kW

N_d is average number of days in month

$t_{heat,on}$ is time in seconds required to provide the required heat output

The time, $t_{heat,on}$, is split into a number of heating 'on' slots, based on the time step of the simulation model.

The heating 'on' time slots are evenly spread over the morning and evening periods, until the morning period is full (because its duration is much shorter than for the evening) then additional slots are added to the evening period.

At some point the heat demand will be too much to accommodate in a bimodal heating pattern, when the boiler is running at minimum rate. At this point the model allows the boiler heat rate to increase for all the time slots equally until the maximum output is reached.

When the boiler can no longer provide the required heat output using maximum output and bimodal timings, the 'on' time is allowed to expand into a full unimodal heating pattern (07:00 to 23:00). Initially the time slots are assumed to be at minimum boiler output, increasing, as necessary.

When maximum output is again reached, the heating mode is switched to continuously on (00:00-24:00). The required energy is distributed evenly over the whole day, if the required output is more than the boiler can supply in a single day then the boiler output is limited to its maximum output. In practice boilers with maximum outputs less that approximately 27kW will not be able to meet the highest demand of 20,000kWh/month. In this case the maximum monthly output should replace the 20,000kWh/month figure.

During these space heating periods it is necessary to make an allowance for the duration of the DHW drawoffs which interrupt the space heating demand. This has been done by estimating the time required for DHW production and allowing for this time as the time slots are allocated. The draw-off pattern is based on the tapping cycle M. This is always used but scaled to meet the DHW demand in the scenario. As the DHW demand changes from scenario to scenario the time estimated to allow for the DHW production may result in the time available for space heating being too small to meet demand at 30% part load. In this case the boiler output is allowed to rise to compensate for the shorter on period.

In the context of this document ‘scenario’ means a particular space heating demand and DHW demand combination.

For example:

Boiler with maximum output 24kW and Minimum output 8kW and 106 L/d DHW demand

Table 37 Illustrative heat period distribution at different heat loads

Space heat demand (kWh/month)	Mode	Total Time SH on (h/d)	Average output (kW)	Actual output from simulation (kWh/month)
0	Off	0	0	0.0
200	Bimodal	0.758	8.7*	199.9
1000	Bimodal	4.095	8.0	999.5
2000	Bimodal	8.179	8.0	1998.8
4000	Bimodal	8.677	15.1	3998.0
20000	Continuous	23.579	24	17203.2

*The boiler output has increased here because the DHW draw-off period have overlapped with the calculated space heating (SH) times more than expected.

When the boiler is firing at a rate other than that used in the charging test an adjustment should be made to the rate of charging of the store, it has been assumed that the rate of heating of the FGHRS is proportional to the heat output of the boiler. The adjustment is applied in terms of a multiplier to the energy derived from charging. The multiplier is the ratio of the current space heating output to the minimum rate (as in the charging test). The maximum ratio is

$$\frac{Q_{SH,max}}{Q_{SH,min}} \qquad \textbf{\textit{[69]}}$$

For most boilers this will be approximately 3.33, although the actual ratio depends on how close the power output is to 30% during the charging test. When the boiler is operating between 30% and full load the heat output to the FGHRS is scaled by the following formula:

$$\frac{Q_{SH,max}}{Q_{SH,min}} \times \frac{Q_{SH,Load}}{Q_{SH,max}} \qquad \textbf{\textit{[70]}}$$

$Q_{SH,Load}$ is the output to space heating at this particular time in the day, which must be less than or equal to the maximum space heating output of the boiler.

Changing the way, the heat is allocated throughout the day and by limiting the adjustment for higher firing rates to represent physically possible processes, significantly reduces issues with the current daily simulation models.

DHW production

DHW production and use in SAP is based around the typical UK usage for approximately 100 litres/day. In characterisation of boilers and FGHRS a 'M' load profile is chosen as the baseline for DHW performance. This load profile which is defined as requiring 5.845kWh/day of DHW energy to be supplied, equates to 100.2 litres/day when DHW is delivered at 60°C. [EN13203-2, ErP]. The 'M' DHW heat load profile is referred to schedule 2, in SAP documentation.

The 'M' load profile, has 23 draw-offs (or tappings) varying in energy requirement from 0.105kWh to 1.4kWh at flow rates of 3, 4 and 6 L/minute. Some tappings are required to achieve minimum temperature differences, most must attain 25°C (assuming an inlet temperature of 10°C) before counting useful energy, this can lead to DHW that does not meet the required specifications, known as 'wasted water'. The FGHRS discharge test is run at 6L/min, which is the highest draw off flowrate in the 'M' load profile.

The configuration of the boiler and FGHRS become important at this point, as the amount of water drawn from the FGHRS will depend on this. (See section 2.4 on Configuration). In particular, if the water from the FGHRS is mixed with cooler water in a mixing valve to keep the temperature down to a maximum acceptable by the boiler DHW system then only part of the water entering the boiler will have come from the FGHRS. Alternatively, if the boiler can accept high temperature water then the whole flow could pass through the FGHRS. In the following analysis it is assumed that the water from the FGHRS (whether mixed with cold water or not) will enter the boiler to provide additional heat up to the DHW set point temperature.

The EN13203-2 tapping pattern requires only a minimum temperature is reached (typically 25°C) for most tappings. However, the boiler is set to achieve the temperature required for the most onerous tappings, generally 'dish-washing' type tappings, requiring a minimum DHW exit temperature of 55°C. This means that the whilst the FGHRS unit could supply water to meet the standard tappings directly at say, 30°C, in practice, the DHW will pass through the boiler and be heated to 55°C (or whatever the DHW setpoint is on the boiler). Thus, only part of the energy required for each tapping is supplied by the FGHRS and the remainder by the boiler.

During the characterisation tests, the maximum boiler DHW exit temperature (or setpoint) needs to be recorded.

The tapping volume depends on the scenario. SAP calculates the DHW demand based on the occupancy of the property which in turn is determined by the floor area of the property. In this simulation the DHW demand is allowed to vary from 61 L/day to 236 L/day in 21 steps, as in previous versions of this work. The 'M' tapping is scaled to the size of the DHW draw-off required by the scenario.

Let the energy for each tapping in the load profile be $Q_{tapping,i}$ where i is the tapping number.

The total energy for the standard 'M' load profile is:

$$Q_{M,pattern} = \sum_{i=1}^{i=23} Q_{tapping,i} = 5.845\ kWh/day \qquad \textbf{\textit{[71]}}$$

The total volume of the standard ‘M’ profile is:

$$V_{M,pattern} = \frac{3600 \times Q_{M,pattern}}{c_w \Delta T_{DHW}} L/day \qquad \textbf{\textit{[72]}}$$

Where ΔT_{DHW} is the difference in temperature between the cold-water inlet temperature to the FGHRS and the boiler DHW exit temperature (K) and c_w is the specific heat of water(kJ/LK).

For each tapping in the scenario, the draw-off energy required is:

$$Q_{scenario,tapping,i} = \frac{V_{scenario} \times Q_{tapping,i}}{V_{M,pattern}}\ kW \qquad \textbf{\textit{[73]}}$$

Where $V_{scenario}$ is the total required DHW volume for the scenario under study (between 61 and 236 L/day).

Assuming that the same increase in temperature is maintained then the minimum volume of each tapping is defined by:

$$V_{min,scenario,tapping,i} = \frac{3600 \times Q_{scenario,tapping,i}}{c_w \Delta T_{DHW}} L \qquad \textbf{\textit{[74]}}$$

Where $V_{min,scenario,tapping,i}$ is the minimum required DHW volume for tapping *i* under this scenario. Based on the current temperature rise of the DHW (ΔT_{DHW}) and specific heat of water c_w.

And the duration of each scenario tapping is determined by the flow rate for that tapping:

$$t_{scenario,tapping,i} = \frac{V_{min,scenario,tapping,i}}{F_{tapping,i}} \quad minutes \qquad \textbf{\textit{[75]}}$$

Where

$F_{tapping,I}$ is the flowrate defined for tapping i, in L/min

The start times for each tapping are assumed to remain unchanged from those defined in the standards. So, for each tapping i, the start time and duration are defined. This information is transferred to the daily simulation model, to determine when the DHW is being drawn off. During this time period it is assumed that the boiler will fire to make up any short fall in exit temperature required for the individual tapping. The flowrate is as defined in the standard for the relevant tapping.

If the boiler can accommodate high DHW inlet temperatures, then the full flow will pass through the FGHRS. If the boiler has to use a mixing valve to restrict the DHW inlet temperature, as was the case with the tested boiler and most boilers in the market, then only a fraction of the feed water may pass through the FGHRS.

For the case with no mixing valve:

Over each time step (Δt, seconds), the volume through the FGHRS ($\Delta V_{tapping,i}$) is:

$$\Delta V_{tapping,i} = \frac{\Delta t \times F_{tapping,i}}{60} L \qquad \textbf{[76]}$$

For the case of a mixing valve:

$$\Delta V_{tapping,i} = \left(\frac{\Delta t \times F_{tapping,i}}{60}\right) \times \left(min\left(\frac{(T_{mix} - T_{cold})}{(T_{store} - T_{cold})}, 1\right)\right) L \qquad \textbf{[77]}$$

If the store temperature (T_{store}) is less than the mixing valve set point (T_{mix}) then all the water goes through the FGHRS. If the store temperature is greater than the mixing temperature, cold water is bled into the feed to the boiler to keep the temperature to the required mixing temperature, which results in less water passing through the FGHRS.

One further alternative may be possible, this is where a bypass valve is used to divert the hot water from the store directly to the DHW system if the water exceeds a certain temperature, however to meet the requirements of the EN13203-2 tapping test, this would have to be set at 55°C or greater. Whilst this may be possible in practice, the proposed testing regime requires an average flow/return temperature of 50°C, and therefore the FGHRS store will never reach a sufficiently high temperature to allow the bypass to operate, therefore testing is not possible in this configuration. Such systems may or may not have a mixing valve and will be treated accordingly.

It is possible that a single external FGHRS may have multiple entries applicable to both the mixing valve configuration and the unmixed feed situation, the SAP assessor would have to choose the correct configuration to select the correct data, for the calculation.

Summing savings in the Daily Model

The daily simulation model gathers the terms of equations [*66*] or [*67*] together in a spreadsheet model. The equations are solved numerically. A stepwise integration of equation [*66*]/[*67*] is performed with a time step set at 10 second intervals, to ensure rapidly changing conditions at the start of draw offs are adequately captured. At each time step equation [*66*]/[*67*] is solved using the current store conditions, the parameters U_c, U_{ch}, U_{dis}, and U_{ch2} determined from the test data, space heating input and DHW flows based on the analysis above. Having determined the energy content of the store the average store temperature can be calculated based on equation [*34*].

Since store temperature and thermal mass (and hence the initial energy content of the store) at the start of the day is not known, it is necessary to start with a guess and to iterate over the day until the start of day store temperature matches the end of day store temperature and thermal mass. The spreadsheet model uses the Excel Solver functionality to do this.

Over the day, the heat obtained from the FGHRS is determined by summing the energy flows through the FGHRS based on equation [*65*]. The total for a month is determined by multiplying by the average days in a month (N_d). This is called the Indirect saving on the spreadsheet model.

The indirect saving only applies when the space heating load is greater than zero, in the model.

6.3.4 Additional combi losses

Combi losses, in the form of wasted water, can occur when the boiler fails to provide water of the correct temperature at the boiler exit during the EN13203-2 test. Losses due to this wasted water are dealt with in the efficiency determined in the test.

However, in SAP there is also a parameter called ‘Additional Combi Loss’ which is a measure of the energy lost in satisfying the daily hot water demand, because of lukewarm water being thrown away as ‘too cold’ whilst waiting for pipework to fill with warmer water. Some of this ‘loss’ is offset against space heating requirements. Combi losses are defined in Table 3 of SAP 2012 which deals with losses in the primary and DHW circuits and keep hot functions. For combi boilers the primary circuit loss is set to zero, but additional losses are specified in SAP Tables 3a, 3b and 3c.

SAP Table 3a is for combi boilers that have not had DHW function tested to a recognised standard (e.g. EN13203-2), these are default values for various combi types with or without keep-hot facilities, but no default values are given for boilers with FGHRS systems of any sort.

SAP Tables 3b and 3c are combi boilers with DHW test results to the standards. Here boilers with FGHRS are given specific loss values, based on the parameter F_1 (or F_2 and F_3). In comparison to standard instantaneous combi boilers the saving excludes the wasted water determined in the EN13203-2 tests. So specific boilers, can have a precise combi loss based on the test data of the underlying boiler.

In the current BRE methodology it is assumed that if there is a keep hot facility then the saving (in the model) against combi loss will be zero and no additional savings are possible, but for these boilers an additional saving is given in equation G5, which is based the combi loss from Tables 3a, 3b or 3c.

If there is no keep hot facility then some additional savings may be possible against the combi loss. These savings (in current methodologies) are based around the assumption that the default combi loss of approximately, 600 kWh per year, applies to all situations. A certain proportion of this loss is estimated to be saved and added to the monthly total saved along with the direct and indirect savings.

However, if the boiler has DHW test data then the baseline will not be a combi loss of 600 kWh/year. This may well lead to impossible results, with more being saved by combi loss correction than is available to save.

It seems that any reduction in the combi loss needs to come in SAP itself rather than in the FGHRS methodology, to avoid problems with mismatching the combi loss assumed in the model with the actual combi loss determined when using SAP. However, it is unlikely that SAP2012 will be changed before its end of life, so an interim method will probably be necessary to cope with calculations on FGHRS. This will have to make suitable changes to the entries in the PCDB files for SAP2012 to accommodate, both boilers with DHW test data and those without.

The problem primarily occurs because add on FGHRS units are not necessarily tested with all the boilers they are sold with. This means that either the data from the boiler the FGHRS was tested with is required (but not currently recorded in PCDB, i.e. F1, F2 or F3 determined from hot water test data) or it is assumed that the boiler will use the default additional combi loss, which means that some of the test data is not utilised or the combi loss is calculated based on the base combi boiler model. The latter seems to be the case in the SAP programs used in this study.

It is believed this would provide the fairest method of calculating combi loss (corrections) for boilers with FGHRS. Since the majority of the potential market for add on FGHRS units, is with new install boilers, which will have DHW test data (to give them best performance under SAP), most SAP assessments will use Table 3b/3c. In rarer cases where the unit has been added to a boiler without DHW test data, the default values need to be used, which will give a poorer result, but that would be the case even without the FGHRS

SAP Tables 3b and 3c could then need to be adjusted to allow for losses both with and without keep-hot options. SAP Table 3a, should be used as a default value for system matched with boilers not tested for DHW performance, an additional entry maybe required to represent reduced combi losses for boilers with storage FGHRS. Best FGHRS saving results would always be obtained where DHW test data is available and published in SAP.

It is suggested, that for SAP2012, where entries do not relate to specific combinations of FGHRS and boiler, two entries be created, one entry will assume that the boiler will have DHW data and use SAP Tables 3b/3c to calculate the additional combi loss. The second entry will be for a generic boiler where the combi loss is unknown. To achieve this, we need to establish a default additional combi loss for a modern boiler and then implement a variation of the methodology to give results which can then be used with SAP Table 3a for default boilers.

Data from the PCDB (assuming the combination boiler is combined with a FGHRS) gives approximate additional combi losses ranging from 0.8 to 91 kWh/month with the mean of around 31 and standard deviation of 12 kWh/month. If we assume the default value should not put manufacturers who have tested at a disadvantage, then we could suggest a figure between the mean value and the default value of 50 kWh (from 600kWh/year in table 3a). The mean plus one standard deviation gives around 45 kWh/month which is close to the default (non-FGHRS) combi loss value. There are two options here, firstly it could be assumed that for boiler/FGHRS combinations which don't have DHW test data then the default combi-losses from table 3a are used without correction. This is the simplest to implement but would mean there is no reduction in combi-loss which may mean savings are underestimated. Secondly, based on the data from the PCDB a flat rate default saving for FGHRS is used. Based on the PCDB data above it could be suggested that a suitable value is for a saving of 5 kWh/month for all systems falling into this category, the second method is harder to implement but does give a small additional benefit for FGHRS which would probably be realised in practice.

In summary, it has been decided that any correction to the additional combi loss used in future SAP version should not be addressed by the methodology for determining savings but should use the existing (or enhanced) mechanisms within SAP.

However, to ensure minimum disruption of the current SAP 2012 procedure, if an add-on FGHRS is paired with a boiler without DHW test data, then the default combi-loss values suggested above should be used. If paired with a boiler with DHW test data then the combi-loss values should be extracted from SAP Tables 3b and 3c in SAP. The only way this can be practically implemented in SAP2012 is to have two entries in the PCDB for FGHRS that could possibly be combined with boilers that do not have DHW data. One entry would be used for boilers with DHW test data and the second for those without DHW test data.

Future SAP procedures may wish to consider additional lines representing saving for systems using FGHRS to Table 3a where default values must be used.

As a topic in its own right, the methodology to determine 'additional combi-losses' needs to be revisited to ensure that the values used are representative of real-life operations.

6.3.5 Calculation of monthly savings

The direct saving is added to the indirect saving to determine the overall monthly saving. Any changes to combi loss are to be dealt within SAP itself, preferably by using data from the DHW tests on the boiler or Boiler + FGHRS.

This procedure is repeated for all possible scenarios, that is for each of the 6 space heating loads, each of which is calculated for 21 DHW demands, for a total of 126 scenarios.

Over each of the space heating loads an equation of the form

$$SavingduetoFGHRS(kWh\ DHW\ energy), Y = a.ln(X) + b.X + c \qquad \textbf{[78]}$$

Is fitted, to provide the 3 constants (a, b, and c) at each space heating load.

Where a, b and c are the constants to be determined and X is the monthly hot water energy requirement and Y is the saving predicted from the model for this X.

This procedure needs to be performed twice, once assuming there is no keep hot facility and once assuming there is a keep hot facility present.

Finally, the two lots of the 6 sets of parameters are then used to create the entry in the PCDB. This is as currently done.

Mathematically, the presence or absence of a mixing valve will make a difference to the performance of the combination of boiler and FGHRS. However, the overall effect of this is smaller than originally anticipated. For SAP2012, our recommendation is that the difference can be ignored, as to include it would mean a proliferation of entries in the PCDB, leaving SAP assessors in doubt as to which FGHRS entry to choose to represent the system under consideration. By default, all entries should be calculated assuming a mixing valve is present, this will ensure the majority of SAP assessments provide the most accurate data.

For later versions of SAP, it is recommended that boiler PCDB entries should have an indication whether they can accept high temperature DHW feed water. By default, it should be assumed they cannot. The additional data could be accommodated in the PCDB by having additional fields in each entry to cover each possible combination ie. Keep hot/ No keep hot & mixing valve/ no mixing valve. The selection of the boiler would then ensure the correct FGHRS data is used.

The remainder of the procedure is as previously described in SAP FGHRS document and also in Annex G of SAP 2012.

6.3.6 Summary of major differences between original and new methods

Although the new methodology is based on the original and alternate methods for calculating SFGHRS energy savings there are a number of significant differences:

Experimental testing has been modified with more rigorous conditions and changes to charging and discharging tests. See Annex C for more details.

Data from experimental testing will be fitted with a trend of exponential nature in order determine heat transfer coefficients for cooling, charging and discharging.

In the new model, the periods which heating is enabled during the day will be based on the requirements of the heat load/ DHW load scenario being tested, the required heat load will be spread evenly over the day starting with a bimodal regime, continuing with a unimodal regime and finally continuous heating as the boiler reaches its maximum output for each of the regimes. Previously it was assumed to be on 0600-0900 and 1500-2300, no matter what the heat load was. This led to impossibly low and impossibly high heating rates, which had a major impact on the predicted FGHRS performance.

The minimum heat rate will be defined as that as in the experiment test work (which should be 30% output) and the maximum will be the maximum space heating output of the boiler as designated by the manufacturer.

DHW draw-off start times are as in the ‘M’ DHW heat load profile (called schedule 2 in SAP/PCDB), the durations depend on the scenario. The length of the tapping is determined by assuming the boiler will always heat the DHW to its DHW setpoint and water will be supplied at the rate in the schedule. Only the total energy supplied for each tapping will vary as the scenario changes allowing draw off duration to be calculated.

The quantity of water passing through the FGHRS will depend on the configuration of the system. There are now 2 options available, systems with a mixing valve that is assumed to mix the water from the FGHRS down to 30°C before entering the boiler and systems where the water is assumed to pass directly from the FGHRS into the boiler. The latter option should only be used with boilers that can support high temperature DHW inlet feeds (ie those that can handle pre-heated water from solar systems). This means that there may need to be additional entries in PCDB to indicate such units.

The charging factor is scaled linearly between 1 (= normally 30% output load) and maximum output load, leading to in most cases a maximum factor of approximately 3.33. This is determined from the heat load as described above.

Recharging of the store during discharge will be handled in the charging function, it is assumed that the boiler will run at an average of the maximum space heating rate during a draw-off. This is included as a scale factor for charging unless there is separate recharging data available from older versions of the discharge test.

The correction for ‘wasted water’ as part of the ‘additional combi-losses’ calculation has been removed from the current calculation. This was based on the default values in SAP Table 3a, however, as many boilers now have DHW test data and use SAP Table 3b/3c, it is not correct to make this correction in the general methodology as it is a function of the boiler used, which is not defined (in cases where the FGHRS is an ‘add-on’) until the SAP assessment takes place.

This needs further work on future SAP procedures. For current SAP 2012 procedures, it is proposed that the any ‘combi-loss’ correction is based on the current SAP Tables 3a, b and c. For storage FGHRS that are combined with boilers without DHW test data it is suggested that a second entry in the PCDB be used for the default case, this would allow for a small reduction in the additional combi-loss, it is suggested that this may be 5 kWh/month.

Having removed the corrections for ‘combi losses’ the difference between the results with and without ‘keep-hot’ facility is now very small, just the wasted water efficiency difference in the DHW standard tests. Again, this means a change to SAP Table 3a may be required in the future to allow for default values for SFGHRS with and without keep-hot facilities.

For SAP10 and beyond, the entry for the FGHRS in PCDB will now have an extra entry or extended fields for the data with and without a mixing valve present. The SAP assessor will need to carefully select the correct version of the data to use in the specific circumstances, linking this with data in the boiler entry for high temperature DHW feed, will help the SAP assessor choose valid combinations.

This means that all exiting data for FGHRS will need recalculating.

6.4 Comparison of New Model to Experimental Results

The FGHRS saving simulation model described in Section 6.3.3, has been run using data previously provided by stakeholders. This has allowed savings to be calculated in SAP2012 for the 3 properties that have been studied. This data has also been compared to the savings determined by laboratory-based testing on the DHLTR.

The simulation model has been run using 2 different sets of data provided by the manufacturer for the model of SFGHRS device that has been tested on the DHLTR. This data mainly follows the testing regime laid out in the BRE FGHRS SAP document, although some of the temperature ranges have been extended. Some parameters such as mixing temperature and DHW exit temperature for the simulation were set to the same as used in DHLTR testing programme so that the results can be compared. Other parameters, such as masses and volumes of water and boiler/ boiler + FGHRS efficiency were used as supplied. The combi loss factor has been based on that determined by the SAP program for the base boiler used, this has been consistent throughout the analyses. However, this may have led to higher FGHRS savings than possible, when using the original and alternate calculation methodologies because of the default assumptions in the original and alternate methodologies regarding additional combi-losses. To explain this further:

The BRE and alternate methodologies assume that the additional combi loss is the default 600 kWh/year (from SAP Table 3a) and derive an energy saving due to the storage FGHRS of something like 30-40 kWh per month based on this.

However, the boiler we have used in both the experimental work and the SAP assessments has EN13203-2 test data, and so uses SAP Table 3b. The combi loss from this is around 11-12 kWh per month, a much lower figure than the default 50 kWh/month (12 x 50 = 600 kWh).

So, the saving predicted by the method should be:

50 – 30 (for example) leaving 20kWh/month Combi loss which is fine.

But in practice we get:

12 – 30 leaving a combi loss of -18 kWh/month which is actually a heat contribution, this is not possible.

This is why the combi loss correction has been removed from the methodology and assessments should rely on SAP table 3b or c where possible or additional work needs to be done to Table 3a to provide sensible default values for FGHRS using boilers without DHW test data.

As mentioned above, the manufacturer of the storage FGHRS had supplied 2 sets of data to characterise the FGHRS. These are for the same device but appear to be based on different boilers, since the boiler efficiencies were different in each case. Parameters for PCDB/SAP have been derived from both data sets and for this comparison with the laboratory data, the boiler chosen in the SAP calculation was the same as that used in the laboratory testing. It is expected that the 2 sets of data should provide similar results.

Using the new methodology the parameters for the PCDB that were calculated (for no keep hot case and with the assumption that a mixing valve is present and set to 33°C) for both data sets were:

Table 38 Parameters calculated from new methodology - first data set

No Keep Hot			
SH load (kWh/month)	a log	B linear	c (const)
0	0.0	0.0826	0
200	1.3	0.1860	-2.3
1000	4.1	0.1821	-10.4
2000	7.1	0.1846	-21.4
4000	10.4	0.1815	-34.3
20000	12.2	0.2115	-41.1

Table 39 Parameters calculated from new methodology - second data set

No Keep Hot			
SH load (kWh/month)	a log	B linear	c (const)
0	0.0	0.0910	0
200	1.8	0.2365	-3.1
1000	4.1	0.2442	-9.1
2000	10.2	0.2334	-33.6
4000	13.2	0.2299	-45.6
20000	15.5	0.2512	-55.6

Where the space heating load does not match with the exact loads above, the three parameters (a, b and c) are interpolated between the two closest space heating load values.

These data are entered into SAP to give the following savings in DHW required energy (not gas):

Table 40 300 W/K Property SAP predicted DHW energy savings based on new FGHRS performance simulation model

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1st Data set	48.7	42.4	43.0	36.4	32.9	9.9	9.3	10.5	10.7	37.2	42.4	47.6	371.1
2nd Data set	61.3	53.5	54.5	46.6	42.3	10.9	10.3	11.6	11.7	47.7	53.7	59.9	464.0

Table 41 105 W/K Property SAP predicted DHW energy savings based on new FGHRS performance simulation model

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1st Data set	30.7	26.8	27.6	23.9	22.6	7.2	6.7	7.6	7.7	24.4	27.0	29.9	242.1
2nd Data set	39.4	34.5	35.5	30.9	29.2	7.9	7.4	8.4	8.4	31.5	34.8	38.4	306.4

Table 42 500 W/K Property SAP predicted DHW energy savings based on new FGHRS performance simulation model

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1st Data set	54.8	48.2	49.3	42.9	36.7	10.6	10.0	11.3	11.4	43.8	48.5	53.5	420.9
2nd Data set	67.6	59.6	61.2	53.7	38.3	11.7	11.0	12.4	12.5	55.1	60.4	66.0	509.6

These figures go into line (63)m of SAP as per SAP 2012 Appendix G.

Then using SAP 2012, the gas energy required for water heating can be determined [line (219)m] which gives the following results for the 300W/K property:

Table 43 Comparison of original and new methodologies - monthly gas energy requirements

SAP predicted DHW gas use (219m) (kWh/month)	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Annual Totals**
Boiler alone (for IFGHRS)	231	203	213	190	186	170	163	180	180	197	210	225	**2349**
Current SAP IFGHRS	188	165	170	149	143	128	119	136	137	154	168	182	**1838**
Boiler alone (for SFGHRS)	200	175	181	159	154	139	130	147	148	166	179	194	**1971**
Current SAP SFGHRS method	32	17	23	13	26	123	116	131	132	18	21	28	**681**
SFGHRS – 1st data set, new method	145	127	133	118	117	127	119	135	136	124	131	140	**1552**

SFGHRS – 2nd data set, new method	131	115	120	107	106	126	118	134	134	112	119	126	**1448**

It can be seen that the new method predicts considerably smaller savings than the current FGHRS calculation method. This is partly because the model is considerably improved and also now the combi losses have been assessed using the boiler DHW data, providing a result which does not lead to more loss being saved than existed originally.

When this data is compared to the data determined from the laboratory-based tests on the DHLTR, it can be seen that the FGHRS data derived from the new method matches more closely:

Table 44 Comparison of laboratory data with predictions from new methodology - SFGHRS 300 W/K property

SAP predicted DHW gas use (219m) (kWh/month)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Totals
Lab data for SFGHRS, based on M DHW load	142	125	133	121	124	135	126	144	146	132	133	139	**1600**
Lab data for SFGHRS, based on L DHW load	166	145	152	135	133	125	116	133	135	143	151	161	**1695**
SFGHRS – 1st data set, new SAP method	145	127	133	118	117	127	119	135	136	124	131	140	**1552**
SFGHRS – 2nd data set, new SAP method	131	115	120	107	106	126	118	134	134	112	119	126	**1448**

Table 45 Comparison of laboratory data with predictions from new methodology - SFGHRS 105 W/K property

SAP predicted DHW gas use (219m) (kWh/month)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Totals
Lab data for SFGHRS, based on S DHW load	89	79	86	82	88	110	102	117	118	92	88	87	**1139**
Lab data for SFGHRS, based on M DHW load	98	86	91	83	84	94	87	100	101	89	91	95	**1099**
SFGHRS – 1st data set, new SAP method	108	95	99	88	86	92	86	97	98	92	98	105	**1146**
SFGHRS – 2nd data set, new SAP method	99	87	90	80	78	91	86	96	97	84	89	96	**1074**

Table 46 Comparison of laboratory data with predictions from new methodology – SFGHRS 500 W/K property

SAP predicted DHW gas use (219m) (kWh/month)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Totals
Lab data for SFGHRS, based on M DHW load	172	152	159	144	144	149	138	158	160	154	160	167	**1856**
Lab data for SFGHRS, based on L DHW load	184	161	168	149	146	136	126	145	147	157	167	178	**1864**
SFGHRS – 1st data set, new SAP method	153	134	140	123	124	136	128	145	146	129	138	148	**1643**
SFGHRS – 2nd data set, new SAP method	139	121	126	111	122	135	126	143	145	116	125	134	**1543**

These data show that the agreement is good between the new model and the laboratory data at smaller loads, but as the load increases the there is a deviation between the lab data and the model. For the smaller property the agreement is good approximately 97-103% of the lab value (based on Lab M tapping data), with the 300 W/K property the agreement is around 91-96% and with the 500 W/K property the agreement is about 83-87% of the laboratory determined gas use for DHW values, i.e. showing a greater saving than achieved in laboratory testing. This is much closer than the current method and data for the SFGHRS under study where the agreement is only about 41% of the laboratory value.

To determine the sensitivity of the results to the assumption that a mixing valve is present or not, the above data has been recalculated assuming there is no mixing valve. These results assume the boiler identified in SAP can accept water at temperatures up to the maximum test temperature.

Table 47 Comparison of calculated data with and without mixing valve - SFGHRS 300 W/K property

SAP predicted DHW gas use (219m) (kWh/month)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Totals
SFGHRS – 1st data set, new SAP method	145	127	133	118	117	127	119	135	136	124	131	140	**1552**
SFGHRS – 1st data set, new SAP method no mixing valve	140	123	129	116	116	126	118	134	135	122	128	135	**1522**
SFGHRS – 2nd data set, new SAP method	131	115	120	107	106	126	118	134	134	112	119	126	**1448**
SFGHRS – 2nd data set, new SAP method no mixing valve	128	113	118	106	107	125	117	132	133	111	117	124	**1432**

Table 48 Comparison of calculated data with and without mixing valve - SFGHRS 105 W/K property

SAP predicted DHW gas use (219m) (kWh/month)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Totals
SFGHRS – 1st data set, new SAP method	108	95	99	88	86	92	86	97	98	92	98	105	**1146**
SFGHRS – 1st data set, new SAP method no mixing valve	107	94	98	87	85	91	86	97	97	91	97	104	**1136**
SFGHRS – 2nd data set, new SAP method	99	87	90	80	78	91	86	96	97	84	89	96	**1074**
SFGHRS – 2nd data set, new SAP method no mixing valve	99	87	91	81	79	90	85	96	96	84	90	96	**1073**

Table 49 Comparison of calculated data with and without mixing valve – SFGHRS 500 W/K property

SAP predicted DHW gas use (219m) (kWh/month)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Totals
SFGHRS – 1st data set, new SAP method	153	134	140	123	124	136	128	145	146	129	138	148	**1643**
SFGHRS – 1st data set, new SAP method no mixing valve	147	128	134	119	123	135	127	143	145	124	133	142	**1600**
SFGHRS – 2nd data set, new SAP method	139	121	126	111	122	135	126	143	145	116	125	134	**1543**
SFGHRS – 2nd data set, new SAP method no mixing valve	133	117	122	108	116	134	125	142	143	114	121	129	**1504**

It can be seen that the difference when it is assumed that a mixing valve is not present, in the cases studied, is relatively small, around 1 to 3%. This would indicate that, at least for the implementation into the existing SAP2012 procedure the difference can be neglected, thus generally simplifying the procedure for the Assessor attempting to survey a property and removing the need for a change in SAP2012. As most boilers cannot accept high temperature

DHW feed water, then by default SAP2012 data should be recorded with a mixing valve in place. For more accurate assessments in SAP 10 and onwards this should still be considered as an influence on the results and extended data sets be used to record and use this information.

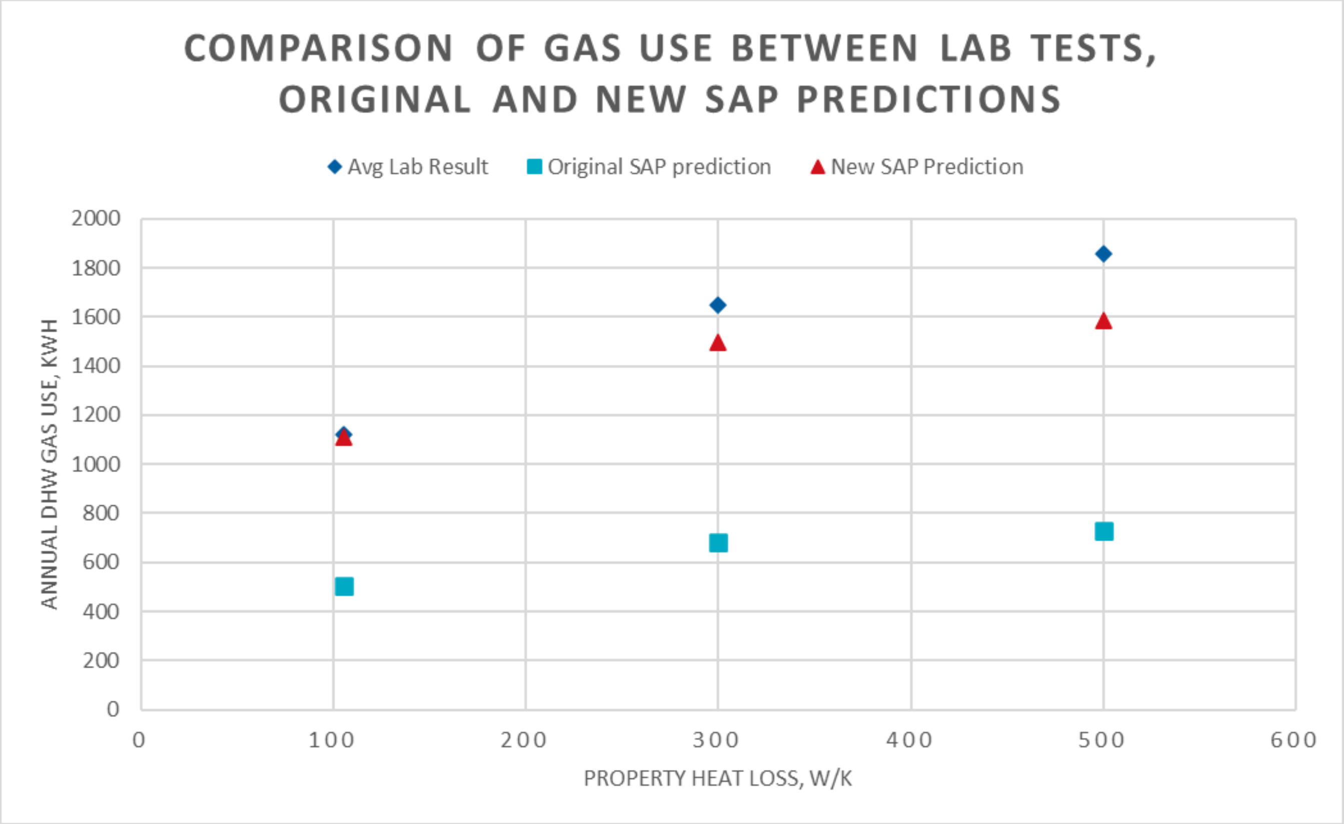


Figure 12 Comparison of predicted gas use between laboratory and old and new SAP methodologies for storage FGHRS

For the instantaneous FGHRS unit the results are:

Table 50 Comparison of laboratory data with predictions from new methodology - Instantaneous FGHRS 300 W/K property

SAP predicted DHW gas use (219m) (kWh/month)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Totals
Lab data for IFGHRS, based on M DHW load	188	165	172	152	149	139	129	148	150	160	170	183	**1904**
Lab data for IFGHRS, based on L DHW load	186	163	169	149	144	126	116	134	135	155	167	180	**1824**
IFGHRS current SAP method	188	165	170	149	143	128	119	136	137	154	168	182	**1838**

The SAP procedure for this instantaneous does not use any of the SAP Appendix ‘G’ calculations, just the direct efficiency based on an EN13203-2 test and a correction to the combi loss in SAP. This appears to work well, and the result agrees between 96% to 100% dependant on the lab test used.

7 Conclusions and Recommendations

7.1 Conclusions

Discussions with BEIS and Stakeholders highlighted issues with the current methodology used to determine savings that are attributable to the use of FGHRS. The current method has been developed over several versions of SAP and some of its assumptions have been shown to be erroneous. Other methods developed by a variety of interested parties have smoothed out some issues but have introduced other biases, whilst missing some of the major existing issues.

The testing of FGHRS in a laboratory setting whilst maintaining the dynamic interaction of space heating and the supply of DHW has shown that current methods in SAP for determining the performance of instantaneous FGHRS systems show good agreement with laboratory results. They are significantly over-estimating the savings due directly to the use Storage FGHRS.

DHW gas use predicted currently by SAP for IFGHRS compared to laboratory testing show predictions are very close varying between 96 to 101% of the laboratory results.

DHW gas use predicted currently by SAP for SFGHRS compared to laboratory testing show much larger discrepancies with values ranging from 40 to 42.5% of the laboratory results.

As a result of this work a detailed reassessment of both the current (BRE) and proposed alternative methods for assessing the performance of storage FGHRS has been completed. Since none of the reviewed methods were entirely appropriate nor match the laboratory testing data, a new model and methodology has been developed. This much more accurately represents the performance of FGHRS technologies.

DHW gas use predicted by the new methodology when included in SAP for SFGHRS compared to laboratory testing show closer agreement with values ranging from 83 to 103% of the laboratory results.

The savings predicted by the new method are much lower than previously claimed. However, these values are now backed up by the experimental evidence.

The adjustments to ‘additional combi-loss’ (shown as ‘wasted water’) in the previous methodologies have been removed and combi-losses based on SAP Tables 3b and 3c should be used wherever possible. Default values in SAP Table 3a for FGHRS combined with boilers with or without keep hot facilities need to be revisited for future versions of SAP. For SAP2012 it is unlikely that it will be possible to change these tables, therefore the only changes that can be made will be in the PCDB data. It is possible that some FGHRS devices will need 2 entries in the table. One entry assuming a default boiler (i.e one that has no DHW test data) and second entry to be used with boilers that have DHW test data. The main text discusses this in more detail.

The testing regime essentially follows the previous version with some improvements to ensure more consistent results, specifically tighter testing tolerances.

Existing data must be recalculated to ensure it is on a consistent basis. This may cause issues if the data originally supplied show unacceptable deviations from either the original or new testing regime, in this case they should probably be replace by default data, or the manufacturer given the option to submit new data. Also, the definition of what constitutes an instantaneous or storage FGHRS may affect some of the existing entries.

Whilst EN13203-7 has shown some promise, in its current form it has been shown to under predict savings from FGHRS. Also, it does not fit well with SAP’s month by month calculations, it has been decided for the present not to employ this standard. However, it should be reconsidered when it is finally ratified. It is thought that the flue temperature employed is probably too low for UK conditions and needs to be increased to at least 50°C, to provide comparable data to that collected now.

7.2 Recommendations

Based on the outcome of this review, Kiwa make the following recommendations:

- A distinction is made between instantaneous and storage FGHRS based on the volume of liquid in the device. It is suggested that minimum DHW volume should be greater than 2 Litres or if condensate is stored this should be greater than 2 Litres to qualify. Devices featuring solid materials to retain heat do not qualify as storage devices unless they meet the liquid volume requirements.
- Boilers with FGHRS defined as instantaneous should be tested to EN13203-2, the results directly entered into PCDB, and treated as they are currently (i.e. with reduced combi-loss via SAP Tables 3b and 3c).
- The new methodology for determination of savings from Storage FGHRS is adopted by BRE for all future submissions of SFGHRS.
- The current testing regime is retained but tightened. New entries with data falling outside that specified must be rejected. Although to provide for transferring existing entries data these restrictions will be relaxed to meeting the original test conditions.
- For SAP 10 and onwards, separate entries or extend data fields to the PCDB for Storage FGHRS may be required to represent combinations of boiler/FGHRS that require a mixing valve to restrict boiler DHW inlet temperature and those that do not. This may be combined with:
    - Boilers on PCDB should indicate whether they can accept DHW inlet water at full FGHRS temperature or require a mixing valve. This could also apply to solar preheat.
- Additional combi-loss in future SAP (Table 3a) is modified to account for default combi boilers with FGHRS and with or without keep-hot facilities, for cases when the boiler does not have DHW test data. If the boiler does have DHW test data it has been assumed that the correction to combi losses specified in SAP Table 3b and 3c, can be

applied to the boiler + FGHRS combination. This may be an oversimplification and requires more research.

- As a possible extension, PCDB entries for FGHRS are modified to include DHW test parameters to enable determination of combi-loss from SAP Tables 3b and 3c. So FGHRS units that can be added to multiple boilers have a consistent set of data.
- All entries for FGHRS in PCDB are to be recalculated, based on original data submitted, to the new methodology if possible. If the data originally supplied show unacceptable deviations from either the original or new testing regime they should be replaced by default data, or the manufacturer given the option to submit new data. Some entries may have to be moved from the SAP appendix G Table to the main database.
- Create new FGHRS submission procedure document from the contents of this report.
- It has been shown that combination boilers (without FGHRS) produce DHW at much higher efficiency when the boiler is preheated by space heating operation, further work is suggested to ensure that this is truly reflected in SAP and also its impact on savings due to FGHRS are assessed more fully.

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Appendix A Mathematical Nomenclature

Notation	Parameter
A	heat transfer area m^2
C	Constant of integration
c_f	Specific heat of dry flue gas kJ/kg.K
c_s	Specific heat of steam kJ/kg.K
c_{store}	Average specific heat of the stored water in the FGHRS and its materials of construction, kJ/kg.K
c_w	specific heat of water kJ/kg.K
$F_{tapping,i}$	Flow rate of each draw off, L/min?
i	Tapping number in a profile
K	Thermal capacity of FGHRS construction materials and water contained within. kJ/K
L	Specific latent heat of evaporation of water kJ/kg
$\dot{m}_{c,out}$	Mass rate of condensate leaving FGHRS kg/s
$\dot{m}_{DHW}$	Mass rate of DHW
$\dot{m}_f$	Mass flow rate of dry flue gas leaving FGHRS kg/s
$\dot{m}_{s,in}$	Mass rate of steam entering FGHRS kg/s
$\dot{m}_{s,out}$	Mass rate of steam leaving FGHRS kg/s
m_{store}	Total mass of the FGHRS and water contained within it, kg
$\dot{m}_w$	Mass rate of water entering FGHRS kg/s
N_d	average number of days in month
ΔQ_{store}	Change in heat content of store for a small time-increment, kJ
$Q_{boiler,output}$	boiler output in kW
Q_{SH}	Space heating demand
$Q_{SH,min}$	Space heating output rate – part load, 30%, kJ/s
Q_{store}	Instantaneous heat content of the stored water in the FGHRS, kJ
$Q_{tapping,i}$	Energy for individual tappings in a profile, kJ or kWh

Notation	Parameter
$Q_{w,in}$	Heat rate of water entering FGHRS kJ/s
$Q_{w,out}$	Heat rate of water leaving FGHRS kJ/s
Δt	A small time-increment, s, and Time step size
t	Time, s (or minutes if so indicated in the text
$t_{heat,on}$	time in seconds required to provide the required heat output
$t_{scenario,tapping,i}$	duration of each scenario tapping, minute
ΔT	temperature difference between the store and the surrounding environment, K
ΔT_{DHW}	Temperature rise of the DHW, K
ΔT_{store}	Change in average store temperature, K
T_{amb}	Ambient temperature, K
$T_{c,out}$	Temperature of condensate leaving FGHRS, k
T_{cold}	Temperature of cold hot water supply to the FGHRS, °C
$T_{f,in}$	Temperature of dry flue gas entering FGHRS, K
$T_{f,out}$	Temperature of dry flue gas leaving FGHRS, K
T_{flue}	Average temperature of flue gases passing through FGHRS, °C
T_{init}	Store temperature at start of test
T_{mix}	mixing valve set point
$Q_{c,out}$	Heat rate of condensate leaving FGHRS kJ/kg
$Q_{charging}$	Rate of heat added to the store in the FGHRS from boiler flue gases (dry + steam), kJ/s
$Q_{cooling}$	Rate of heat removed from the store in the FGHRS by heat loss mechanisms, kJ/s
$Q_{demand,month}$	desired monthly required in kWh (= heat output from boiler)
$Q_{DHW,demand}$	hot water demand

Notation	Parameter
$Q_{DHW,demand,saved}$	FGHRS saving in terms of DHW demand
$Q_{discharging}$	Rate of heat removed from the store in the FGHRS with outflow of stored water, kJ/s
$Q_{f,in}$	Heat flow rate of dry flue gas entering FGHRS kJ/s
$Q_{f,out}$	Heat flow rate of dry flue gas leaving FGHRS kJ/s
$Q_{gas,saved}$	saving in gas use in summer mode (i.e. no space heating)
Q_{loss}	Heat loss rate, kJ/s
$Q_{M,pattern}$	Total energy for the ‘M’ load profile, kJ or kWh
$Q_{s,in}$	Heat rate of steam entering FGHRS kJ/s
$Q_{s,out}$	Heat rate of steam leaving FGHRS kJ/s
$Q_{scenario,tappings,i}$	Energy for individual tappings in a profile, kJ or kWh
$Q_{SH,max}$	Space heating output rate – full, kJ/s
T_{ref}	Reference temperature, 0°C=273.15K
T_{store}	Average store temperature °C
$T_{w,in}$	Temperature of water entering FGHRS, K
$T_{w,out}$	Temperature of water leaving FGHRS, K
U	overall heat transfer coefficient kJ/kg.K.m^2
U_c	Overall heat transfer coefficient of cooling of FGHRS kJ/K
U_{ch}	Overall heat transfer coefficient of charging kJ/K
U_{ch2}	2nd Overall heat transfer coefficient of charging, determined from discharge test kJ/K
U_{dis}	Overall heat transfer coefficient of Discharging kJ/K
$\Delta V_{tapping,i}$	volume through the FGHRS for each time step
$V_{M,pattern}$	Total volume of the ‘M’ profile, L
$V_{min,scenario,tapping,i}$	minimum required DHW volume for tapping i under particular scenario, L
$V_{scenario}$	Total required DHW volume for the scenario under study (between 61 and 236 L/day)
η_{boiler}	DHW efficiency of the boiler alone
η_{FGHRS}	DHW efficiency of the boiler with the FGHRS

Please note some of the discussion around the standards EN13203-2 and EN13203-7 refers to the nomenclature used in these standards. For these sections please refer to the nomenclature definition in the relevant standard.

Appendix B Details of Integrations for New Model Construction

Cooling

$$\boldsymbol{\frac{dT_{store}}{dt} = \frac{U_c}{K}(T_{store} - T_{amb})}$$

$$\frac{dT_{store}}{(T_{store} - T_{amb})} = \frac{U_c}{K} dt$$

$$\int \frac{dT_{store}}{(T_{store} - T_{amb})} = \int \frac{U_c}{K} dt = \frac{U_c}{K} t + C$$

Substitution:

$$\mathrm{B} = (T_{store} - T_{amb})$$

$$\int \frac{dT_{store}}{(T_{store} - T_{amb})} = \int \frac{1}{B} dT_{store} = \int \frac{1}{B} d\mathrm{B} = ln(B)$$

$$\therefore ln(T_{store} - T_{amb}) = \frac{U_c}{K} t + C$$

Initial condition: at time t=0, the store temperature is the initial store temperature, T_{init}.

$$\therefore ln(T_{init} - T_{amb}) = \frac{U_c}{K}(0) + C$$

$$\therefore ln(T_{init} - T_{amb}) = C$$

$$\therefore ln(T_{store} - T_{amb}) = \frac{U_c}{K} t + ln(T_{init} - T_{amb})$$

$$e^{ln(T_{store} - T_{amb})} = e^{\frac{U_c}{K} t + ln(T_{init} - T_{amb})}$$

$$(T_{store} - T_{amb}) = e^{\frac{U_c}{K}t} e^{ln(T_{init} - T_{amb})} = e^{\frac{U_c}{K}t}(T_{init} - T_{amb})$$

$$\therefore T_{store} = (T_{init} - T_{amb}).e^{\left(\frac{U_c.t}{K}\right)} + T_{amb}$$

Charging

$$\frac{dT_{store}}{dt} = \frac{U_{ch}}{K}\left(T_{flue} - T_{store}\right) - \frac{U_c}{K}(T_{store} - T_{amb})$$

$$K\frac{dT_{store}}{dt} = U_{ch}T_{flue} + U_cT_{amb} - T_{store}(U_{ch} + U_c)$$

Assuming all parameters apart from T$_{store}$ are constant with respect to time. Use the following substitutions

$$A = U_{ch} + U_c$$

And

$$J = U_{ch}T_{flue} + U_cT_{amb}$$

$$\therefore \frac{dT_{store}}{dt} + \frac{AT_{store}}{K} = \frac{J}{K}$$

Integrate using the integrating factor method. For a differential equation of the form

$$\frac{dy}{dx} + Py = Q$$

The solution is $Iy = \int IQ.dx$ where I is the integrating factor, defined by $I = e^{\int P.dx}$

$$IT_{store} = \int I\frac{J}{K}.dt$$

$$I = e^{\int\frac{A}{K}.dt} = e^{\frac{At}{K}}$$

$$e^{\frac{At}{K}}T_{store} = \int e^{\frac{At}{K}}\frac{J}{K}.dt$$

$$e^{\frac{At}{K}}T_{store} = \frac{K}{A}e^{\frac{At}{K}}\frac{J}{K} + C$$

$$e^{\frac{At}{K}}T_{store} = \frac{J}{A}e^{\frac{At}{K}} + C$$

Initial condition: At initial time t=0, the store temperature is the initial temperature $T_{store} = T_{init}$

$$e^{\frac{A(0)}{K}}T_{init} = \frac{J}{A}e^{\frac{A(0)}{K}} + C$$

$$T_{init} = \frac{J}{A} + C$$

$$C = T_{init} - \frac{J}{A}$$

$$\therefore e^{\frac{At}{K}}T_{store} = \frac{J}{A}e^{\frac{At}{K}} + T_{init} - \frac{J}{A}$$

$$T_{store} = \frac{J}{A} + \left(T_{init} - \frac{J}{A}\right)e^{\frac{-At}{K}}$$

Rearrange to form:.

$$T_{store} = \frac{J}{A} + \left(\frac{AT_{init}}{A} - \frac{J}{A}\right) e^{-\frac{At}{K}}$$

$$T_{store} = \frac{J - (J - AT_{init})e^{-\frac{At}{K}}}{A}$$

Substitute the J and the A within the brackets

$$T_{store} = \frac{J - \left(\left(U_{ch}T_{flue} + U_cT_{amb}\right) - (U_{ch} + U_c)T_{init}\right) e^{-\frac{At}{K}}}{A}$$

$$T_{store} = \frac{J - \left(U_{ch}T_{flue} - T_{init}U_{ch} + U_cT_{amb} - T_{init}U_c\right)e^{-\frac{At}{K}}}{A}$$

$$T_{store} = \frac{\mathrm{J} - \left(U_{ch}\left(T_{flue} - T_{int}\right) - U_c(T_{init} - T_{amb})\right) e^{-\frac{At}{K}}}{A}$$

Substitute remaining J and A elsewhere:

$$\therefore T_{store} = \frac{\left(U_{ch}T_{flue} + U_cT_{amb}\right) - \left(U_{ch}\left(T_{flue} - T_{int}\right) - U_c(T_{init} - T_{amb})\right) e^{\frac{-(U_{ch}+U_c)}{K}t}}{(U_{ch} + U_c)}$$

Discharging

$$\frac{dT_{store}}{dt} = \frac{U_{ch2}}{K}\left(T_{flue} - T_{store}\right) - \frac{U_c}{K}(T_{store} - T_{amb}) - \frac{U_{dis}}{K}(T_{store} - T_{cold})$$

$$K\frac{dT_{store}}{dt} = U_{ch2}T_{flue} - U_{ch2}T_{store} - U_cT_{store} + U_cT_{amb} - U_{dis}T_{store} + U_{dis}T_{cold}$$

$$K\frac{dT_{store}}{dt} = U_{ch2}T_{flue} + U_cT_{amb} + U_{dis}T_{cold} - T_{store}(U_{ch2} + U_c + U_{dis})$$

Assume values of all U and T parameters apart from T_{store} constant with respect to time.

Substitute:

$$V = U_{ch2}T_{flue} + U_cT_{amb} + U_{dis}T_{cold}$$

And

$$B = U_{ch2} + U_c + U_{dis}$$

To give

$$K\frac{dT_{store}}{dt} = V - BT_{store}$$

Rearrange

$$\frac{dT_{store}}{dt} + \frac{B}{K}T_{store} = \frac{V}{K}$$

Integrate using the integrating factor method. For a differential equation of the form

$$\frac{dy}{dx} + Py = Q$$

The solution is $Iy = \int IQ.dx$ where I is the integrating factor, defined by $I = e^{\int P.dx}$

$$IT_{store} = \int I\frac{V}{K}.dt$$

$$I = e^{\int \frac{B}{K}.dt} = e^{\frac{Bt}{K}}$$

$$e^{\frac{Bt}{K}}T_{store} = \int e^{\frac{Bt}{K}}\frac{V}{K}.dt$$

$$e^{\frac{Bt}{K}}T_{store} = \frac{K}{B}e^{\frac{Bt}{K}}\frac{V}{K} + C = \frac{V}{B}e^{\frac{Bt}{K}} + C$$

Initial condition: At initial time t=0, the store temperature is the initial temperature $T_{store} = T_{init}$

$$e^{\frac{B(0)}{K}}T_{init} = \frac{V}{B}e^{\frac{B(0)}{K}} + C$$

$$T_{init} = \frac{V}{B} + C$$

$$C = T_{init} - \frac{V}{B}$$

$$\therefore e^{\frac{Bt}{K}} T_{store} = \frac{V}{B} e^{\frac{Bt}{K}} + T_{init} - \frac{V}{B}$$

$$T_{store} = \frac{V}{B} + \left(T_{init} - \frac{V}{B}\right) e^{-\frac{Bt}{K}}$$

Rearrange to form in equation [31].

$$T_{store} = \frac{V}{B} - \left(\frac{V}{B} - T_{init}\right) e^{-\frac{Bt}{K}}$$

$$T_{store} = \frac{V - (V - BT_{init})e^{-\frac{Bt}{K}}}{B}$$

Substitute the V and the B within the brackets

$$T_{store} = \frac{V - \left(\left(U_{ch2}T_{flue} + U_c T_{amb} + U_{dis}T_{cold}\right) - (U_{ch2} + U_c + U_{dis})T_{init}\right) e^{-\frac{Bt}{K}}}{B}$$

$$T_{store} = \frac{V - \left(U_{ch2}T_{flue} - T_{init}U_{ch2} - T_{init}U_{dis} + U_{dis}T_{cold} - T_{init}U_c + U_c T_{amb}\right)e^{-\frac{Bt}{K}}}{B}$$

$$T_{store} = \frac{\mathrm{V} - \left(U_{ch2}\left(T_f - T_{int}\right) + U_{dis}(T_c - T_{init}) + U_c(T_{amb} - T_{init})\right) e^{-\frac{Bt}{K}}}{B}$$

$$T_{store} = \frac{\mathrm{V} - \left(U_{ch2}\left(T_f - T_{int}\right) - U_{dis}(T_{init} - T_c) - U_c(T_{init} - T_{amb})\right) e^{-\frac{Bt}{K}}}{B}$$

Substitute remaining V and B

$$\therefore T_{store} = \frac{\left(U_{ch2}T_f + U_{dis}T_c + U_c T_{amb}\right) - \left(U_{ch2}\left(T_f - T_{int}\right) - U_{dis}(T_{init} - T_c) - U_c(T_{init} - T_{amb})\right) e^{\frac{(U_{ch2}+U_{dis}+U_c)}{K}t}}{(U_{ch2} + U_{dis} + U_c)}$$

Appendix C Laboratory testing of FGHRS for submission for inclusion into PCDB

Performance data

In order for the energy savings potential to be estimated by the SAP, performance data comprising of laboratory test data and thermophysical properties concerning the system are required. This section presents the performance data required.

Ideally, each combination of boiler and FGHRS should be tested as below. However, as some FGHRS are marketed as ‘add-ons’ for a number of different makes and types of boiler, the testing requirement would become too onerous as the number of combinations could be very large. Similarly, where families of boilers with essentially the same performance are to be tested. In these cases a single representative boiler can be used to characterise the FGHRS using the test described below.

Thermophysical properties

The thermophysical properties of the system required are:

- Weight of heat exchanger(s) in kg
- Total Volume of water/condensate in the heat exchanger(s) in litres (include both primary and secondary water)
- Specific thermal capacity of the heat exchanger(s) material(s) in kJ/kg/K
- With separate store then the volume of hot water (DHW) in the store in litres
- Volume of DHW in heat exchanger in the store in litres
- Specified maximum total length (m) and diameter (mm), insulation conductivity (W/m/K) and thickness (mm) of connecting pipework between store and heat exchanger.
- Specified maximum total length (m) and diameter (mm), insulation conductivity (W/m/K) and thickness (mm) of connecting pipework between store and cold water feed to boiler.
- Specified minimum height between the store’s highest domestic water level and the highest water level in the heat exchanger.
- Properties of the new instantaneous combi boiler (no “keep-hot” facility) used in the tests
- Boiler name and model
- Minimum firing input rate in central heating mode (kW net)
- Maximum heat output rate in central heating mode (kW)
- BED Declared efficiency at full and 30% part load

Laboratory data

Four sets of laboratory tests are required to characterise the key properties of the system. All tests are conducted using a new combi boiler without keep-hot facility, having a SEDBUK efficiency of at least 90% for condensing boilers or SEDBUK efficiency of at least 80% for non-condensing boilers.

Any connecting pipes must be at manufacturer's specified maximum length and maximum diameter and minimum insulation thickness and conductivity.

The height of the store above the heat exchanger must also be at its minimum height as specified by the manufacturer if water is circulated by gravity (natural convection).

The tests are:

> No 1 Charging test – The rate of temperature rise of the heat store whilst the boiler is providing space heating at a known steady rate
>
> No 2 Cooling test – The rate of decline in the temperature of the heat store during standby.
>
> No 3 Discharging test – The rate of decline in the temperature of the heat store whilst the boiler is providing a hot water service at a steady rate, with firing disabled.
>
> No 4 Summer hot water tests – The difference in total (including rejected water) and useful efficiency during a 24-hour tapping schedule for the same boiler with and without the FGHRS operational.

If the manufacturer of the boiler requires that inlet DHW water temperature is controlled using a mixing valve, then this must be in place for test No. 4. For the discharge test No.3 the water flowrate and temperature shall be determined before any mixing valve.

If the FGHRS is an add-on unit that could be combined with either boiler that requires a mixing valve or a boiler that does not require a mixing valve. Then test No 4 shall be done in both configurations using the same boiler for all tests.

Test results from No 1 to No 3 are used to model a 24-hour temperature profile of the heat store over an average day in the heating season, and the fourth is used to estimate the instant energy recovered when the boiler is providing domestic hot water only.

Tests 1 to 3 are concerned with the thermal properties of the heat store only. If the system does not have a heat store or deferred savings are not claimed, tests 1 to 3 are not required.

Table 1 - Example data formats for tests 1, 2 and 3

	Temperatures recorded at least every 15s for test 2 and every 5s (preferably 1s) for tests 1 and 3						
Time	Cold water supply	FGHRS exit	Cold water boiler inlet	Store position (the number depends on store height and volume)			Ambient air
				1	2	…nth.	
s	°C‡	°C‡	°C‡	°C‡	°C‡	°C‡	°C‡
0	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx
1	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx
2	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx
	….	….	….	….	….	….	….
	….	….	….	….	….	….	….
7199	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx
7200	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx

‡ are average temperatures over the time interval.

Table 2 - Example data formats for test 1 additional data

	Temperature of				
Time	Boiler exit flue	Flue exit after heat exchanger	Heating primary flow	Heating primary return	Heating primary flow rate
Seconds	°C †	°C †	°C ‡	°C ‡	Litres/min ‡
0	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx
1	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx
2	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx
….	….	….	….	….	….
….	….	….	….	….	….
7199	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx
7200	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx

† are spot measurements and ‡ are average temperature of the time interval.

The boiler firing rate, fuel temperature and pressure (if gaseous fuel), and gross calorific value (or higher calorific value) and carbon dioxide concentration must be recorded every 20 minutes during test 1.
The average ambient temperature must be 20±2°C. Note: If a reference fuel (eg G20) is used the stated reference value may be used instead of a measured value.

Test No. 1 - Store charging test

This test is required to establish the warming rate of the store as a function of its temperature under typical central heating conditions.

The system under test must be fitted to a suitable boiler, as specified above.

Start with the boiler OFF.

To ensure consistent start conditions for the charging test, cold water is to be fed into the unit under test at 10±2°C at 6L/min and the outlet temperature monitored until the difference between the exit temperature and the inlet temperature is less than 1°C and within 10±2°C these conditions are then to be maintained for a minimum of 1 minute. Preferably, this data should be included with the results presented, however, evidence of test start temperatures being within range at the start of the charge test would be acceptable.

Turn off water flow.

Switch boiler on.

Measurements begin when the system is warmed by circulating primary water through the heating circuit under the following conditions:

- An average primary boiler flow and return temperature of 50±1°C
- Flow temperature of 53±2°C.
- Return temperature of 47±2°C.
- at 30% of part load of the nominal maximum space heating output; or at the minimum firing rate for space heating if the minimum output is higher than 30%.

The flow rate and temperatures of the boiler are to be continually monitored and recorded and the average heat rate to space heating over the charging test period should be calculated and recorded. It is also necessary to monitor and record the flue gas temperature at the boiler and FGHRS exits.

The temperature of the heat store at “many” locations is measured at least every 5 seconds (preferably every second) until the store temperature reaches its equilibrium temperature. This will be when the store temperature reaches a value that does not change by more than 0.5 K over 5 minutes.

The ambient temperature of the laboratory air surrounding the boiler and system must remain reasonably constant maintaining an average of 20±2°C, if single ambient temperature measurements are outside the range of 20±2°C then they must be no more than 2°C from the average. The ambient temperature should be monitored at the same rate as other data.

“Many” locations means that temperature sensors are to be located at the top and bottom of the store underneath the insulation on the metal surface and spaced at 100mm intervals vertically if the height of the store is greater than 200mm. The exact position of the sensors should be recorded. If the store is wider than 1m then additional horizontal sensors are to be placed at each side and if wider than 2m spaced at 1m intervals.

An average of 50°C was chosen as this is approximately half-way between the temperatures specified for gas condensing boilers tested at full and 30% part load for the purposes of the Boiler (Efficiency) Directive.

This test will be performed twice, once before the Cooling test and once before the Discharge test, both sets of data are to be supplied for analysis as described in test 2 and 3 below. Data from both tests will be checked to ensure they are within the tolerances and both data sets will be used to determine an average value for the Cooling coefficient. The period between the end of the charge test and the start of the cooling or discharge test should also be recorded.

Test No. 2 - Store cooling test

This test is required to establish the natural cooling down rate of the heat store as function of store average temperature and laboratory temperature.

Firstly, the store is pre-heated as described in the charging test No 1.

When equilibrium is reached (as described above), the boiler is then switched off completely.

After a minimum wait period of 1 minute, the cooling test starts, the boiler is left off until the average store temperature returns to ambient air temperature (±0.5°C) or for 16 hours whichever is longer.

The laboratory air and store temperature at the many locations (see) are recorded at least every 15 seconds. The ambient temperature of the laboratory air surrounding the boiler and system must remain reasonably constant maintaining an average of 20±2°C, if single ambient temperature measurements are outside the range of 20±2°C then they must be no more than 2°C from the average. The ambient temperature should be monitored at the same rate as other data.

The data for this test must include the charging test data and the one-minute minimum transition period and must clearly indicate the start and finish of each period.

Test No. 3 - Store discharging test

This test is required to establish the cooling down rate of the heat store when drawing a constant amount of hot water.

Firstly, the store is pre-heated as described in the charging test No 1.

When equilibrium is reached (as described above), The boiler is then turned off or firing is disabled.

After a minimum wait period of 1 minute, the discharge test is started by drawing domestic hot water from the boiler at a constant rate of 6L/min until the temperature of water leaving the unit under test is within 1°C of the water temperature at the inlet.

Since changes occur very rapidly, the temperature of the heat store at the many locations, the ambient temperature, the cold water inlet temperature and water exiting the unit under test must be recorded at least every 5 seconds (preferably every second).

A constant rate of 6 ± 0.5 litres/min is selected since this is the highest rate in (BS EN 13203):2 No 2 schedule and approximately half the maximum rate of many combi boilers. This must be recorded at the same time intervals as the other logged data. This is the flowrate leaving the store, before any mixing has taken place, this may require additional pipework, to ensure the correct flow is monitored.

The temperature of the cold feed must be maintained at 10°C ±2°C.

The ambient temperature of the laboratory air surrounding the boiler and system must remain reasonably constant maintaining an average of 20±2°C, if single ambient temperature measurements are outside the range of 20±2°C then they must be no more than 2°C from the average. The ambient temperature should be monitored at the same rate as other data.

The data for this test must include the charging test data and the one-minute minimum transition period and must clearly indicate the start and finish of each period.

Test No. 4 - Summer hot water test

This is a 24 hour test required to establish the direct benefits of the FGHRS during hot water production. Tests, with and without the FGHRS are required to follow BS EN13203:2 – using the 'M' heat load profile.

If the FGHRS device is designed to be used on both boilers that require a mixing valve and those that do not, this test must be performed in both configurations.

Additional measurements are required to confirm any reported energy savings are feasible. These are:

- The temperature of the preheated domestic water into the boiler, measured at the same frequency as the cold water supply temperature (into the heat exchanger). If any mixing with cold water occurs, the preheated temperature is taken as the temperature after mixing but before it enters the boiler.
- The temperature of the pre-heated water as it leaves the heat store measured at the same frequency as the cold water supply.
- The integrated energy content over 24 hours of water leaving the heat exchanger but before entering the boiler.

Other required detailed results as specified in EN13203:2 are:

- Total energy content of the hot water produced including any rejected because it is too hot or too cold.
- Useful energy content of the hot water produced excluding any rejected because it is too hot or too cold.
- Energy content of gas used during the tests
- Boiler firing times
- Electricity consumption

Required Test matrix

The specific tests required for entry into SAP2009 or SAP2012 depend on the configuration of the FGHRS unit as in the table below:

Application	Store Cooling Test	Store Charging Test	Store Discharging Test	Tapping test:EN13203:2 with device active	Tapping test:EN13203:2 without the device or with it bypassed
Integral PFGHRD (nonstorage)	N/a	N/a	N/a	Required	N/a
Integral PFGHRD (storage)	Required	Required	Required	Required	N/a
Non-Integral FGHRS or PFGHRD (nonstorage)	N/a	N/a	N/a	Required	Required

Application	**Store Cooling Test**	**Store Charging Test**	**Store Discharging Test**	**Tapping test:EN13203:2 with device active**	**Tapping test:EN13203:2 without the device or with it bypassed**
Non-Integral FGHRS or PFGHRD (storage)	Required	Required	Required	Required	Required
Integral PFGHRD (nonstorage) based on SAP 2005 recognition*	N/a	N/a	N/a	Uses SAP 2005 result	N/a
Integral PFGHRD (storage) based on SAP 2005 recognition*	Uses SAP 2005 result	Uses SAP 2005 result	Uses SAP 2005 result	Uses SAP 2005 result	N/a

* Existing SAP 2005 results may be used to recognise boilers with an integral PFGHRD (on application to BRE); provided the device is the same as that originally tested and that the boiler is an instantaneous combi boiler without a keep hot facility or other hot water storage (see below).

The results of the tests on integral PFGHRD are limited to the boiler brand and make tested and the results of non-integral PFGHRD may be applied to other boiler types provided the adjustments to the estimated potential savings (see SAP Appendix G (G5 or G6)).

Appendix D Timeline and outcome of interaction

The following timeline details the significant interaction between Kiwa and stakeholders, with a summary of the outcome from each interaction

08/11/2019 – Initial interaction with BEIS

BEIS provided a folder of documents relating to the dispute surrounding the existing methodology, including the outcome of the SAP Scientific Integrity Group (SAPSIG)'s involvement in the dispute.

04/12/2019 – Interaction with BRE

BRE were approached to provide details of the existing methodology as well as any raw data and calculations to support the existing FGHRS entries in the PCDB.

In response BRE provided a document explaining the current method [17] as well as several calculation spreadsheets used for the listing of existing entries in SAP and some test data.

09/12/2019 – Notification of the review to all potential stakeholders

Stakeholders were notified that Kiwa had been commissioned to undertake the review. The methodology that would be employed was explained and a request for data and/or equipment to support the project was made.

18/12/2019 – Meeting in Cheltenham between Kiwa and Canetis

The Canetis products were discussed in detail as well as understanding their concerns with the current methodology, the draft standard EN13203-7, and some aspects of SAP. There was general agreement on the methodology to be used in the review.

Canetis supplied documentation detailing alleged inaccuracies in the current method as well as a derivation of 2 methods: the Closed Form Analytical Solution (method 1) and the interim solution (method 2). These were supported by some test data.

09/01/2020 – Meeting in Cheltenham between Kiwa and Group Atlantic (Ideal)

The Ideal products were discussed in detail as well as understanding their concerns with the current methodology, the draft standard EN13203-7, and some aspects of SAP.

Ideal supplied some results of some in house SAP modelling, as well as comments on the draft standard EN13203-7. They also agreed to supply two boilers for testing, one with integrated FGHRS and one without.

16/01/2020 – Meeting in Preston between Kiwa and Baxi

The methodology of the review was explained, and it was agreed that some units would be supplied for testing, namely a boiler with and without SFGRS.

23/01/2020 – Teleconference project update

A teleconference was held between BEIS and Kiwa to discuss and agree the test programme.

30/01/2020 – Meeting at Camden House between Kiwa and the HHIC Boiler Technical Panel

The methodology to be employed during the review was discussed as well as the panels general feelings to the current methodology. Outcome of meetings

12/03/2020 – Teleconference project update

A teleconference was held between BEIS and Kiwa to discuss the initial findings of the test programme. A proposal for further test work was made, which was later agreed.