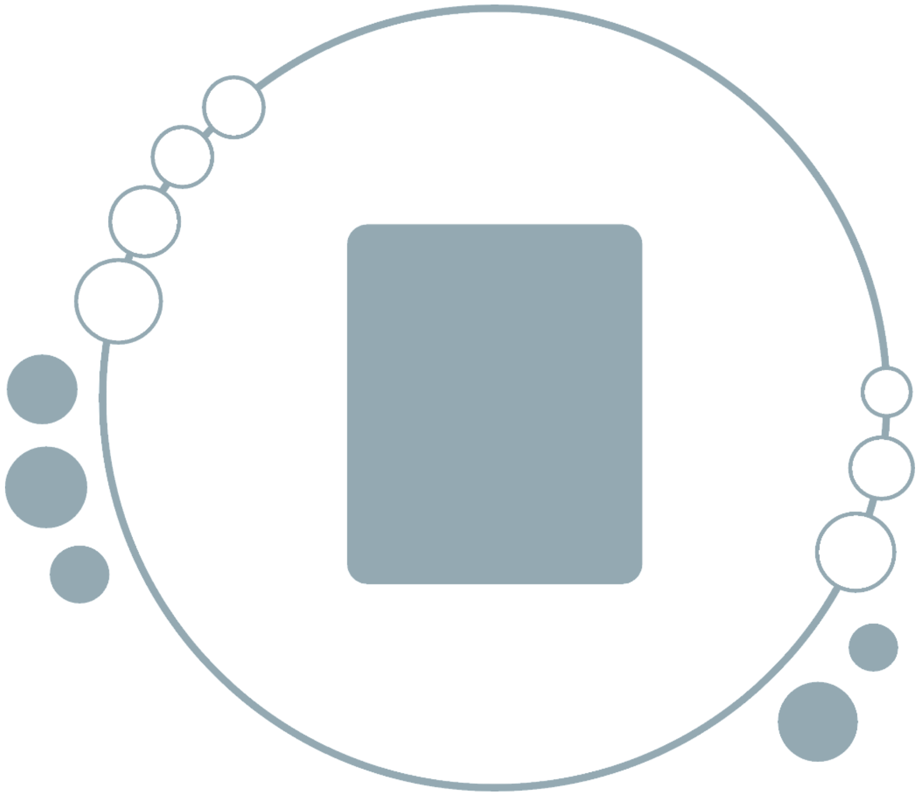

Modelling Gas and LPG Boilers within the Home Energy Model

A technical explanation of the methodology

October 2025

Acknowledgements

This methodology has been developed for the Department for Energy Security & Net Zero by a number of organisations and individuals, including Sustenic, Quidos, Scene Connect, City Science, Hoare Lea, Oxford Brookes University, University of Bath, 10-x, Building Research Establishment (BRE), AECOM, Kiwa Ltd., Loughborough University Enterprises Limited, Chris Martin and John Tebbit.

Quality assurance has been undertaken by a consortium led by Etude, including Levitt Bernstein, People Powered Retrofit, University of Strathclyde's Energy Systems Research Unit, Julie Godefroy Sustainability, and UCL.

Document reference: HEM-TP-14

Document version: v3.0

Issue date: October 2025

Home Energy Model version: HEM 1.0

Contents

Background to the Home Energy Model

What is the Home Energy Model?

The Home Energy Model (HEM) is a calculation methodology designed to assess the energy performance of homes, which will replace the government's Standard Assessment Procedure (SAP).

Where can I find more information?

This document is part of a wider package of material relating to the Home Energy Model.

Home Energy Model technical documentation (e.g. this document)

What: This document is one of a suite of technical documents, which explain the calculation methodology in detail. New documents will be added, and the content amended, when necessary to ensure documentation is sufficiently comprehensive. This will usually, but not always, occur alongside the release of a new version of HEM.

Audience: The technical documentation will be of interest to those who want to understand the detail of how the Home Energy Model works and how different technologies are treated.

The Home Energy Model consultation and government response

What: The Home Energy Model consultation introduces the overhaul to the SAP methodology and sought views on the approach taken by the new Home Energy Model. The Home Energy Model consultation summarises the feedback to the consultation and the actions taken subsequently in development, ahead of the initial release of HEM.

Audience: The Home Energy Model consultation will be of interest to those seeking a general introduction to HEM and its role in government policy on domestic energy performance.

The Home Energy Model reference code

What: The full Python source code for the Home Energy Model core engine has been published as a Git repository. Note the reference code for official HEM wrappers is published separately.

Audience: The reference code will be of interest to those who want to understand how the model has been implemented in code, and those wishing to fully clarify their understanding of the new methodology. It will also be of interest to any potential contributors to the Home Energy Model or those wishing to use it within their own projects.

Related content

This paper sets out the methodology for modelling boilers within the Home Energy Model core engine. See below for other related documents and the relevant module in the reference code.

Related technical documents

Other relevant papers on the core engine include:

- HEM-TP-04 Space heating and cooling demand
- HEM-TP-11 Hot water storage tanks
- HEM-TP-16 Heat emitters
- HEM-TP-17 Controls

For further information on relevant assumptions made within the FHS assessment wrapper, please see:

- HEMFHS-TP-02 FHS space heating and cooling demand assumptions

Code implementation

To understand how this methodology has been implemented in computer code, please see:

src/core/heating_systems/boiler.py

Methodology

The method originates from the Energy Balance Validation (EBV) method[1] and relies on part-load and full-load efficiency values obtained from BS EN 15502-1:2021 tests. The EBV method was chosen as it uses test data that manufacturers are providing already to generate efficiencies. BS EN 15502-1:2021 describe acceptable test procedures for gaseous and liquid boilers respectively. The test data is also based on BS EN 13203-2:2022 to derive hot water performance where available.

In addition to these test standards, the methodology incorporates BS EN ISO 15316-4-1:2017 to calculate boiler case losses, model the cycling behaviour of the boiler, and apply adjustments for boiler installation location.

An overview of the calculation steps to be performed is listed below. A flowchart can be seen in Figure 1.

1. The Home Energy Model (HEM) will provide the energy requirements for the required service and the required flow temperature during the operational hours. For space heating, this is calculated in the emitter module. For water heating with regular boilers, the tank module calls the boiler module. See section 1.

2. For combination boilers, the additional combi loss is calculated and added to the hot water demand. See section 1.1.

3. The current boiler power is calculated based on the boiler minimum modulation and energy demand.

4. The cycling and location adjustments are calculated. See section 2.

5. Calculate the Energy Balance Validation boiler efficiency. See section 3.

6. Calculate final boiler efficiency based on EBV efficiency, cycling adjustment and location adjustment. See section 4.

7. Calculate the energy delivered by the boiler and energy input to deliver that energy depending on energy requirements. See section 5.

[1] https://bregroup.com/documents/d/bre-group/stp09-b02_energy_balance_validation

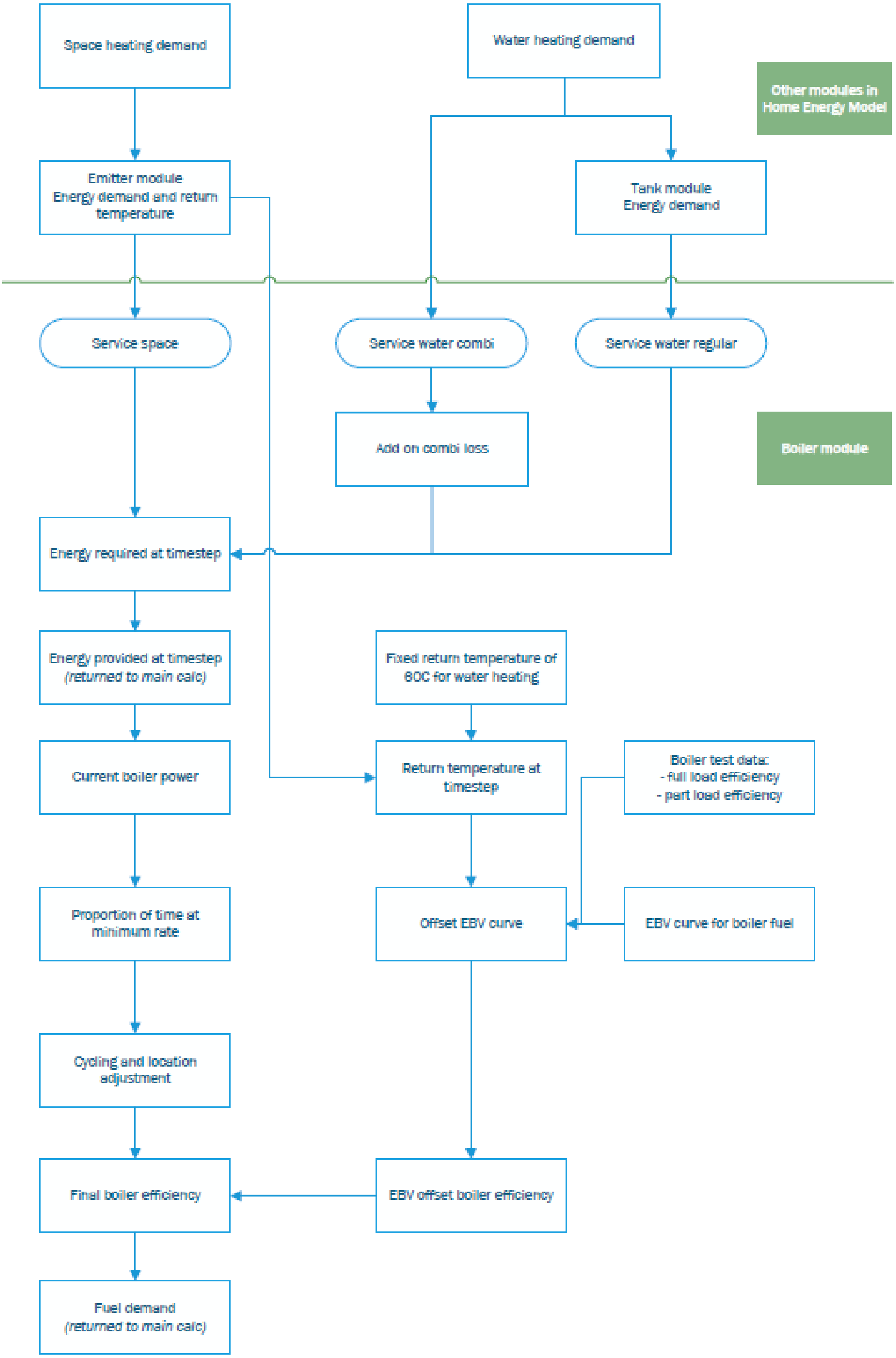

Figure 1 – Flowchart of calculation steps for gas boilers in the Home Energy Model

1. Energy requirement

1.1 Water heating

For water heating services with regular boilers, the energy demand and temperature of hot water is calculated by the storage tank module and is provided as an input to the boiler module.

For water heating services with combi boilers, the energy demand and temperature of hot water is from the hot water demand calculation is used directly (rather than being modified by the storage tank module). The sections below go into more detail on how the combi loss is calculated for different levels of test data provided by the manufacturer.

1.1.1 Combi loss for two additional test results (M & S or M & L)

When test results are submitted for a combination boiler in accordance with medium tapping profile and small or medium and large of BS EN 13203-2, a procedure to calculate combi loss from the test results is as follows:

- Estimate the proportion of rejected energy, r_1 and r_x by retrieving from test results the wasted volume of water, in percentage terms, respectively for cycle M and S or L and dividing each by 200.
- Retrieve from test results the daily fuel consumption in summer mode for profile M and for profile S or L expressed in terms of the net calorific value. Convert to gross calorific terms by dividing each by the conversion factor, f, Table 2, to obtain Q_{FLG} (for profile M) and $Q_{FLG,X}$ (for profile S or L).
- Calculate the summer seasonal efficiency (η_{summer}) in gross calorific terms:

$$\eta_{summer} = \frac{100 \times \left[\left(Q_{dhw} \times (1 + r_x)\right) - \left(5.845 \times (1 + r_1)\right)\right]}{\left[Q_{FLG,X} - Q_{FLG}\right]}$$

where Q_{dhw} is 11.655 kWh/day for cycle L and 2.1 kWh/day for cycle S.

Confirm whether the hot water tests included any active flue gas heat recovery system (FGHRS) and limit the result in step 3 (η_{summer}) to the maximum noted in Table 1.

Fuel type	Natural gas	LPG	Oil
Max. efficiency (%)	88.2	90.3	91.5

Table 1 - Maximum gross efficiency for summer hot water efficiency without FGHRS

- Calculate the heat loss factor F_2 in kWh/day from:

$$F_2 = (\eta_{summer} \times 0.98 \times Q_{FLG} \div 100) - 5.845 \times (1 + r_1)$$

If the result is negative set it to zero.

- Calculate the heat loss factor $\mathrm{F_3}$ (change in wasted energy proportion per litre change in water usage) from:

$$\mathrm{F_3} = \frac{(\mathrm{r_1} - \mathrm{r_x})}{(\mathrm{V_U} - 100.2)}$$

where $\mathrm{V_U}$ = volume of useful water = 199.8 or 36 for Profile L or S respectively.

- These factors are then stored in the PCDB (or future equivalent)
- HEM calculates the combi loss using equation below:

$$Combi\ loss = energy\ demand \times [r_1 + DVF * F_3] \times f_u + [F_2 \times \frac{timestep}{hours\ per\ day}]$$

Where DVF is the daily volume factor. The daily volume factor DVF depends on the daily volume, $DHWU$, and the tapping profiles used for testing as follows:

Tapping profile M and S: if $DHWU$ < 36.0, DVF = 64.2

if $DHWU$ > 100.2, DVF = 0

otherwise DVF = 100.2 – $DHWU$

Tapping profile M and L: if $DHWU$ < 100.2, DVF = 0

if $DHWU$ > 199.8, DVF = -99.6

otherwise DVF = 100.2 – $DHWU$

1.1.2 Combi loss for one additional test result (M only)

When test results submitted for a combination boiler are obtained in accordance with medium tapping profile only using BS EN 13203-2:2022. The procedure to calculate the combi loss from the test results is as follows:

- Calculate the summer seasonal efficiency (η_{summer}) by retrieving the full load- efficiency from the space heating measurements (in %, gross calorific terms), converting from net to gross efficiency, if necessary applying the correction factor from Table 2 and any capping as defined in Table 5.
- Calculate the proportion of rejected energy (r_1) by retrieving from water heating measurements the wasted volume of water in percentage terms and dividing by 200.

- Obtain the daily fuel consumption expressed in terms of the net calorific value in kWh/day. Convert it to gross calorific terms by dividing by the conversion factor, f, to obtain Q_{FLG}.
- Calculate the heat loss factor F_1 in kWh/day where:

$$F_1 = (\eta_{summer} \times Q_{FLG} \div 100) - 5.845 \times (1 + r_1)$$

- If the result is negative, set it to zero.
- These factors are then stored in the Product Characteristic Database (PCDB) or future equivalent.

The Home Energy Model calculates the combi loss using equation below:

$$Combi\ loss = [energy\ demand \times r_1 \times f_u] + [F_1 \times \frac{timestep}{hours\ per\ day}]$$

Where f_u is the daily hot water usage factor. If the daily hot water usage, $DHWU$ is less than 100 L/day then the daily hot water usage factor is f_u = $DHWU$ / 100L, otherwise the daily hot water usage factor is 1.0.

1.1.3 Combi loss for no additional test results

When additional tests are unavailable, a combination loss of 600 kWh/year is assumed.

1.2 Space heating

For space heating services, the energy demand and return temperature during each timestep are calculated by the emitter module and are provided as inputs to the boiler module.

2. Cycling and location adjustment

2.1 Cycling adjustment

During certain conditions, the heating requirement may be lower than the minimum heat produced by a boiler when firing continuously. For on/off boilers the minimum heat output is 100%, so this will be true for all conditions. When the heat requirement is lower than the minimum boiler heat output, the boiler will cycle on/off at its minimum firing rate to produce the required output. Under this condition the heat loss during the off-part of the cycle reduces the hourly efficiency as follows.

The boiler heating efficiency is defined as the useful energy produced divided by the total of the useful and the energy wasted based on the losses method. Therefore, at the minimum firing rate under steady conditions the instantaneous efficiency can expressed as a function of the useful thermal power produced, the rate of heat loss in the flue products and from the case.

$$\eta_{min} = \frac{P_{out,min}}{(P_{out,min} + P_{fl,min} + P_{cs,min})} \tag{1}$$

Where:

η_{min} Instantaneous efficiency

$P_{out,min}$ Useful thermal power produced at minimum firing rate

$P_{fl,min}$ Rate of heat loss in the flue products at minimum firing rate

$P_{cs,min}$ Power case losses at minimum firing rate

This assumes complete combustion which is reasonable because safety and environmental standards demand that only small amounts of CO can be produced.

Similarly, the efficiency when cycling at the minimum rate is:

$$\eta_t = \frac{t_{on} \times P_{out,min}}{(P_{out,min} + P_{fl,min} + P_{cs,min}) \times t_{on} + P_{cs,min} \times t_{off}} \tag{2}$$

Where:

η_t Efficiency when cycling

t_{on} proportion of timestep boiler is cycling at minimum rate

t_{off} proportion of timestep boiler is not cycling at minimum rate

This assumes that the heat lost in the flue products is small when the boiler is off, which is reasonable for condensing boilers as they have fan-assisted flues, which shut-down shortly after the boiler ceases to fire suppressing the natural convective heat losses.

Combining (1) and (2) and rearranging gives:

$$\frac{1}{\eta_t} = \frac{1}{\eta_{min}} + \frac{P_{cs,min}}{P_{out,min}} \times \frac{t_{off}}{t_{on}} \qquad (3)$$

Making the assumption that proportion of heat losses from the case is the same at maximum and minimum power when operated at the same mean water temperature (that it, $\frac{P_{cs,min}}{P_{out,min}}$ is the same as $\frac{P_{cs,max}}{P_{out,max}}$) and adopting the temperature correction noted in BS EN 15316-4-1:2017, Section 6.5.5, equation 46 gives:

$$\frac{P_{cs,min}}{P_{out,min}} = \frac{P_{cs,ref}}{P_{out,ref}} \times \left(\frac{\bar{T}_E - T_{rm}}{\bar{T}_{E,ref} - T_{rm,ref}}\right)^{1.25} \qquad (4)$$

Where:

$P_{cs,min}$ Power case losses at minimum power

$P_{cs,max}$ Power case losses at maximum power

$P_{cs,ref}$ Power at reference temperature (a mean water temperature of 70ºC)

$P_{out,ref}$ Rate of heat loss produced at reference temperature

$\bar{T}_E$ Mean emitter temperature.

T_{rm} Room temperature

$\bar{T}_{E,ref}$ Mean emitter temperature at reference temperature.

$T_{rm,ref}$ room temperature at reference temperature

1.25 is the boiler standby heat loss power law index

Incorporating the temperature correction from equation (4) in equation (3) makes the adjusted efficiency due to cycling:

$$\frac{1}{\eta_t} = \frac{1}{\eta_{min}} + \frac{P_{cs,ref}}{P_{out,ref}} \times \left(\frac{\bar{T}_E - T_{rm}}{\bar{T}_{E,ref} - T_{rm,ref}}\right)^{1,25} \times \frac{t_{off}}{t_{on}} \qquad (5)$$

Table B.3 from BS EN 15316-4-1:2017 gives default values for case heat losses at a mean water temperature of 70ºC when expressed as a fraction of the nominal load.

$$standing\ loss = 4.0 \times (\mathrm{P})^{-0.4}\ /\ 100 \qquad (6)$$

Where:

P is the boiler power at the timestep

Note: This equation has been adjusted to use the current boiler power instead of the nominal power as in the standards to align with lab results. The boiler lab report can be found here: HEM-VAL-05 Lab testing: boiler cycling**.**

When the boiler is firing continuously no adjustment is necessary so $\Delta cyc = 0$.

$$\Delta cyc = \frac{standing\ loss}{(30K)^{1.25}} \times (T_{return\_temp} - T_{bloc,t})^{1.25} \times \frac{t_{off}}{t_{on}} \qquad (7)$$

Where:

Δcyc is the adjustment within the calculation timestep when cycling on/off at the minimum modulation rate

T_{return_temp} is the boiler return temperature.

$T_{bloc,t}$ is the boiler location temperature, which is room temperature when installed inside and outside temperature when outside

$30K$ is the nominal temperature difference in Kelvin between the boiler and test room during the standby loss test (BS EN 15502-1:2021)

Note: The mean emitter temperature has been replaced by the return temperature as the emitter temperature in the HEM model is the final temperature in the timestep and is thus unlikely to be the temperature when the boiler is heating. Additionally, the majority of the water in the boiler is also likely to be the return temperature.

Note: the consultation version of the boiler module assumes the nominal temperature difference between the boiler and the test room is 30K as defined by the standby loss test (BS EN 15502-1:2021). However, in the BS EN 15316-4-1:2017 says the average water temperature is 70C meaning a temperature difference of 50K.

2.2 Location adjustment

A boiler's efficiency reduces when installed outside due to an increase in case heat loss.

The following adjustment is made when the boiler is located outside (when installed inside no adjustment is necessary so $\Delta Loc = 0$)

$$\Delta Loc = \frac{standing\ loss}{(30)^{1.25}} \times \left[\left(T_{return\_temp} - T_{room} \right)^{1.25} - \left(T_{return\_temp} - T_{bloc,t} \right)^{1.25} \right] \quad (8)$$

Where:

ΔLoc is the efficiency adjustment

T_{room} is the room temperature

3. Energy Balance Validation boiler efficiency

A theoretical Energy Balance Validation boiler efficiency is calculated as follows:

1. Determine fuel for boiler type, the fuel for boiler type must be one of natural gas or LPG.
2. Obtain the boiler's BS EN 15502-1:2021 full load[2], η_{FL} and 30% part load[3] gross efficiencies, η_{PL}.
3. Convert net efficiencies to gross efficiencies. Establish whether the efficiency test results are gross or net (i.e. calculated on the basis of gross or net calorific value for the fuel used in the tests). If the efficiency is gross efficiency, proceed to Step 4 of the calculation. If net efficiency, convert efficiency to gross using the following equation with the appropriate factor taken from the test report. For reference, indicative values (only) are reproduced in Table 2.

$$\eta_{gross} = f \times \eta_{net}$$

Fuel	Net-to-gross conversion factor, f
Natural gas	0.901
LPG (propane or butane)	0.921

Table 2 – Illustrative efficiency conversion factors

4. A correction is applied to high test results, this is to correct for observed bias in test results, according to Table 3 and Table 4. The figures are based a meta-analysis carried out in this test report[4].

Fuel	Full-load efficiency (η_{FL})		
	Threshold value (%)	Correction if η_{FL} > threshold	Correction if η_{FL} threshold
Natural Gas	86.0455	- 0.673 (η_{FL} – 86.0455)	0
LPG	87.9555	- 0.673 (η_{FL} – 87.9555)	0

Table 3 - Efficiency correction term for full-load tests

[2] Test conducted with a return water temperature of 60°C
[3] Test conducted with a return water temperature of 30°C
[4] https://bregroup.com/documents/d/bre-group/stp09-b05_meta-analysis_of_boiler_test__results-pdf

Fuel	30% Part-load efficiency (η_{PL})		
	Threshold value (%)	**Correction if η_{PL} > threshold**	**Correction if η_{PL} threshold**
Natural Gas	87.0366	- 0.213 (η_{PL} – 87.0366)	0
LPG	88.9686	- 0.213 (η_{PL} – 88.9686)	0

Table 4 - Efficiency correction term for part-load tests

5. Reduce to maximum gross efficiency values. Table 5 gives the maximum values of gross efficiency for each fuel that may be used. Reduce any greater value (after adjustment according to Table 3 or Table 4) to the appropriate value given in Table 5.

	Condensing boilers			**Non-condensing boilers**		
	Natural gas	**LPG**	**Oil**	**Natural gas**	**LPG**	**Oil**
Full-load	88.298	90.258	91.826	82.892	84.732	86.204
Part-load	97.308	97.626	97.448	88.991	83.811	87.141

Table 5 - Maximum gross efficiency values (in %)

6. From the curve in Figure 2, obtain the average of the theoretical gross boiler efficiency for a return temperature of 60°C and 30°C, then subtract the average of the test results to obtain an offset value.

The resultant offset value is used to shift the theoretical curve, creating an adjusted gross efficiency curve for the boiler (with respect to return water temperature). The efficiency curves are based on fuel characteristics described in the EBV method developed in 2006[5]

[5] https://www.bre.co.uk/filelibrary/SAP/2012/STP09-B02_Energy_balance_validation.pdf

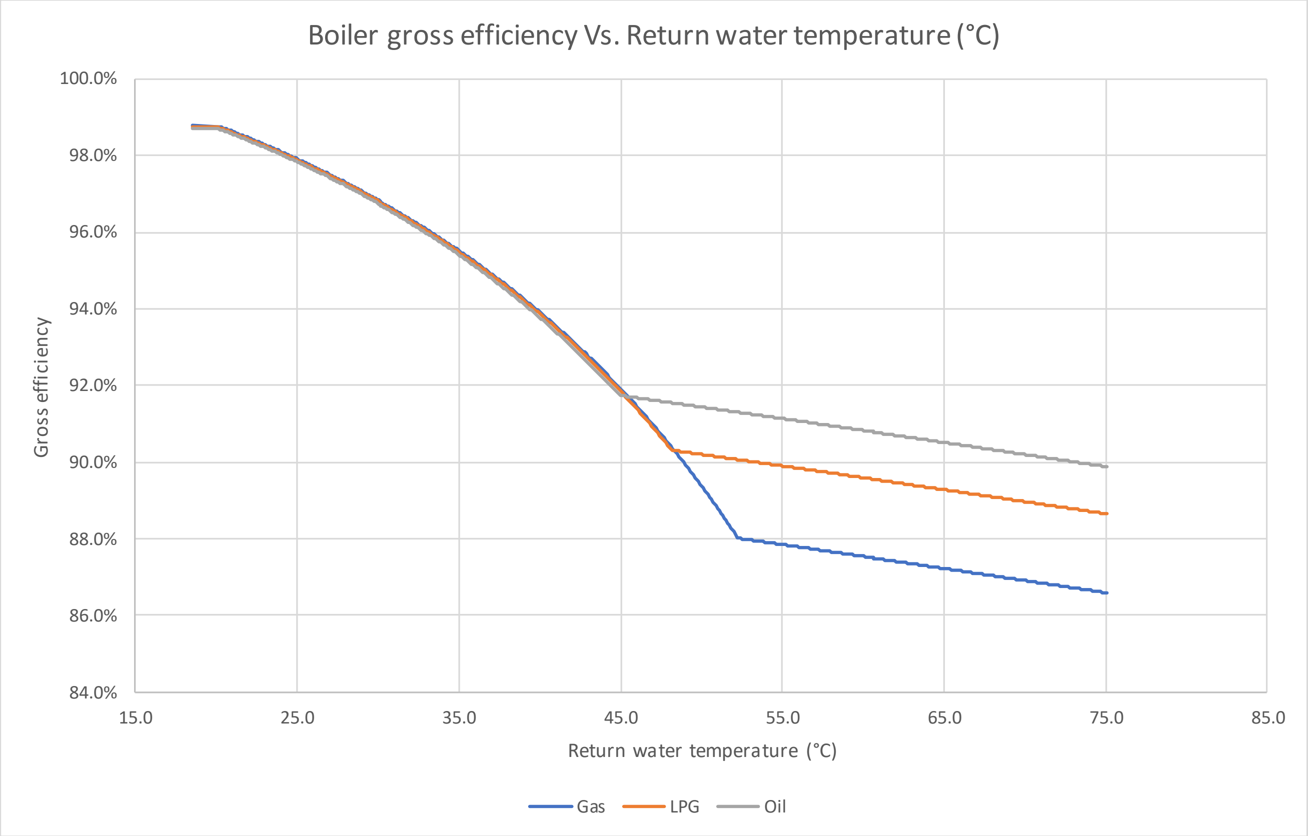

Figure 2 – Theoretical boiler efficiency vs return water temperature

4. Final boiler efficiency

The final boiler efficiency is calculated as follows:

1. For the timestep's return water temperature, obtain the boiler's gross efficiency from the adjusted gross efficiency curve.
2. If the boiler is located outside, calculate the location adjustment as specified in the location adjustment section.
3. Determine if the boiler cycles on/off during the timestep, which will occur if the heat energy requirement is less than the minimum boiler heat output multiplied by the timestep time. If so, calculate the cycling adjustment as specified in the cycling adjustment section. Otherwise, the boiler fires continuously and no adjustment applies. If boiler starts cycling use the corrected full load efficiency as the boiler efficiency before cycling adjustment is applied.
4. Calculate the final boiler efficiency after accounting for any adjustments for location and cycling using formula below.

$$\frac{1}{\eta_{final}} = \frac{1}{\eta_{EBV}} + \Delta Loc + \Delta cyc$$

Where:

η_{final} is the final boiler efficiency used in HEM

η_{EBV} is the boiler efficiency from the Energy Balance Validation method

ΔLoc Location adjustment

Δcyc Cycling adjustment

5. Electricity consumption

Where full-load efficiency and 30% part-load efficiency test results include electrical power measurements, the boiler's electrical energy consumption should be calculated in accordance with the equations below.

$$P_{elec} = circulation\, pump\, power + standby\, power + flue\, fan\;\, power$$

For on/off boilers:

$$P_{elec} = P_{circ} * running\ time + \ P_{SB} * standby\ time\ + \ el_{max} * running\ time$$

For modulating boilers:

$$P_{elec} = P_{circ} * running\ time + \ P_{SB} * standby\ time\ + \ el_{modulating\ flue} * running\ time$$

Where:

el_{min} is part-load electrical power (W)

el_{max} is full-load electrical power (W)

$el_{modulating\ flue}$ is electrical power interpolated between part-load and full-load electrical power (W)

P_{SB} is standby electrical power (W)

P_{circ} is the circulation pump power (W)

Future development

The following features are being considered for integration into the HEM boiler methodology:

- Further fuels (oil and solid fuel boilers)
- Non-condensing boilers
- Storage combination boilers
- Twin range cooker boilers
- Impact of permanent pilot

The combi loss calculation could be improved by relating the calculation to the number of events or volume of water in the test tapping profile instead of spreading the combi loss to every timestep.

This publication is available from: https://www.gov.uk/government/publications/home-energy-model-technical-documentation