BRITISH STANDARD

BS 845-1:1987

Incorporating Amendment No. 1

Methods for

Assessing thermal performance of boilers for steam, hot water and high temperature heat transfer fluids —

Part 1: Concise procedure

Committees responsible for this British Standard

The preparation of this British Standard was entrusted by the Refrigeration, Heating and Air Conditioning Standards Committee (RHE/-) to Technical Committee RHE/10, upon which the following bodies were represented:

Associated Offices Technical Committee
Association of British Solid Fuel Appliances Manufacturers
Association of Shell Boilermakers
Boiler and Radiator Manufacturers Association Ltd.
British Coal
British Combustion Equipment Manufacturers Association
British Foundry Association
British Gas Corporation
Building Services Research and Information Association
Chartered Institution of Building Services Engineers
Department of Energy (Energy Efficiency Office)
Department of Energy (Gas Standards)
Department of the Environment (Property Services Agency)
Domestic Solid Fuel Appliances Approval Scheme
Engineering Equipment and Materials Users Association
Health and Safety Executive
Hevac Association
Institute of Domestic Heating Engineers
Society of British Gas Industries

The following bodies were also represented in the drafting of the standard, through sub-committees and panels:

Association of Consulting Engineers
British Paper and Board Industry Federation (PIF)
Institution of Chemical Engineers
Institution of Mechanical Engineers
National Industrial Fuel Efficiency Service
Water-tube Boilermakers' Association

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Contents

Foreword

This Part of BS 845 has been prepared under the direction of the Refrigeration, Heating and Air Conditioning Standards Committee. Together with BS 845-2 it supersedes BS 845:1972, which is withdrawn.

The revised edition of BS 845 describes, in two Parts, the procedures that should be used and the data that should be collected in order to obtain an assessment of the thermal performance of steam, hot water or high temperature heat transfer fluid boilers, generally of output greater than 44 kW. The results may be based on either the net or the gross calorific value of the fuel.

The procedures described in this British Standard are for thermal performance only but are based on the assumption that boilers are operated during the assessment in such a manner as to comply with relevant safety requirements and the requirements of national environmental legislation.

BS 845 is published in two Parts as follows.

— *Part 1: provides a concise but complete procedure and is convenient for boilers which are thermodynamically simple, i.e. having a single major source of heat input and a simple circuit for water, steam or high temperature heat transfer fluid;*

— *Part 2: provides a comprehensive procedure suitable for all boilers including those with multiple thermal flows to and from the boiler.*

Part 1 applies to boilers which do not condense moisture out of the flue gases. As experience is gained in industry with boilers with this facility, consideration will be given to publishing an addendum to give additional requirements in this respect.

Part 1 provides a straightforward procedure at minimum cost. It is intended to be used in connection with the testing of sectional cast iron, welded steel, shell and simple water-tube boilers for steam, hot water or high temperature heat transfer fluid. More complex boilers should be assessed in accordance with BS 845-2 but, in this context, no definitive division of boilers is possible.

Part 1 is concerned with boilers having conventional firing equipment and fired with solid fuels as normally supplied, fuel oil of standard grades, liquified petroleum gases or natural gas. It may be used also for assessments to be made where plant includes a special form of firing or involves the combustion of an unconventional fuel, the characteristics of which are not readily obtainable, but in such cases heat output should be measured in place of heat input as described in the following paragraph. Where a more detailed assessment is required, Part 2 of this standard should be used.

Part 1 uses the indirect (losses) procedure, in which the heat input is measured or, if not possible, the thermal output and the losses are established. Where the heat input cannot be measured conveniently the heat output may be measured as an alternative provided that the necessary accuracy of measurement can be achieved.

An assessment in accordance with this Part of BS 845 may be required on the following occasions:

a) after the commissioning of new plant or after the recommissioning of modified plant in order to verify compliance with a specification or contractual obligation;

b) whenever the user wishes to determine the current performance of the plant either on a routine basis or due to change of load or other operating conditions or when a change of fuel or a modification to the plant is being considered;

c) whenever the user wishes to check combustion conditions.

Regular assessments in accordance with this Part of BS 845 will enable boiler plant to be monitored in normal operation for optimum efficiency in the interests of fuel conservation.

A British Standard does not purport to include all the necessary provisions of a contract. Users of British Standards are responsible for their correct application.

Compliance with a British Standard does not of itself confer immunity from legal obligations.

Summary of pages

This document comprises a front cover, an inside front cover, pages i to iv, pages 1 to 16, an inside back cover and a back cover.

This standard has been updated (see copyright date) and may have had amendments incorporated. This will be indicated in the amendment table on the inside front cover.

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1 Scope

This Part of BS 845 describes a concise procedure for conducting thermal performance assessments, using the indirect (losses) procedure, to give results within a tolerance of ± 2 percentage points[1)] for boilers for steam, hot water or high temperature heat transfer fluids and for presenting the results in tabular form. Test results are based on either the gross or the net calorific value of the fuel.

This concise procedure provides a convenient means for assessing boilers which are thermodynamically simple, i.e. having a single major source of heat input and a simple circuit for water, steam or high temperature heat transfer fluid, and that do not condense moisture out of the flue gases.

NOTE The titles of the publications referred to in this standard are listed on the inside back cover.

2 Definitions

For the purposes of this Part of BS 845 the following definitions apply.

2.1
assessed losses

any thermal losses established from predetermined data

2.2
gross calorific value

the amount of heat liberated by the complete combustion, under specified conditions, of unit volume of a gas or unit mass of a solid or liquid fuel in the determination of which the water produced by combustion of the fuel is assumed to be completely condensed and its latent and sensible heat made available (see BS 526)

2.3
net calorific value

the amount of heat generated by the complete combustion, under specified conditions, of unit volume of a gas or unit mass of a solid or liquid fuel in the determination of which the water produced by the combustion of the fuel is assumed to remain as a vapour (see BS 526)

2.4
heat input

the heat content of the fuel used during the test based on the gross or net calorific value plus the sensible heat in the fuel above ambient temperature

2.5
heat output

the heat gained by the heat carrier from the boiler during the period of the test

2.6
measured losses

any thermal losses calculated from actual measurements made during the test

2.7
indirect procedure

the determination of thermal performance by the assessment of the thermal losses and the measured thermal input or output. Major thermal losses are determined directly from measured quantities; minor losses are determined directly or assessed and in the case of radiation and convection losses Appendix B gives values

2.8
radiation, convection and conduction losses

the losses from water, steam, combustion air, or gas-backed surfaces prior to the flue gas temperature measurement point and directly from flame to the floor and surroundings of the unit

2.9
test error

the combined error due to sampling, measurements, calculations and assumptions used to obtain test results. The overall effect may be positive or negative

2.10
thermal efficiency

the difference between 100 % and the total percentage losses based on either the gross or net calorific value of the fuel. This is equivalent to the ratio of the useful heat output to the heat input expressed as a percentage

2.11
turn-down ratio

the ratio of maximum and minimum fuel inputs for continuous firing in unit time specified by the manufacturer. This ratio can also be expressed in terms of boiler output provided the appropriate efficiencies are known

3 General

NOTE Where a thermal performance assessment is to be carried out after the commissioning of new plant or after the recommissioning of modified plant, it is necessary for the parties concerned to decide at the plant tendering or ordering stage on the test data required and on the test accuracy and hence the instrumentation to be used (see Appendix B).
It is also necessary for the parties concerned to decide whether the test is to be carried out by the contractor or by an independent body and by whom it is to be witnessed.

3.1 Tests shall represent the intended method and system of operation of the plant under the intended conditions of installation and normal operation.

[1)] One percentage point is one hundredth of the total amount concerned, in this instance, the heat input.

NOTE Attention is drawn to the need for compliance with statutory requirements relating to smoke, grit, dust, SO_2 and NO_X emission.

3.2 Tests shall be carried out at predetermined firing rates, e.g. those corresponding to boiler rated output and to any reduced output of which the firing equipment is capable automatically, e.g. low rate of fire on high/low/off equipment and middle and low rates on firing equipment which fully modulates over a range.

NOTE 1 This may necessitate manually holding the firing rate at a particular setting and will require the availability of sufficient load during the period required to establish steady state (see **5.2**) and for the duration of the test.

NOTE 2 These tests will enable the rated output and turn-down ratios to be verified.

4 Instrumentation

4.1 All measurements shall be made with instruments calibrated in accordance with the manufacturer's instructions. Portable or mobile instruments shall be used unless it can be shown that the sensors of installed instruments have been located correctly (see **5.8**) and the system checked for accuracy.

NOTE A range of typical instruments suitable for the tests described in this standard are listed in Table 1 and their use is acceptable within their stated limits of accuracy.

Table 1 — Typical instruments and their accuracies

Measurement	Instrument	Probable error[a]	Remarks
Fluid flow	Positive displacement	± 1 % reading	Range 10 : 1
	Orifice, nozzle or venturi	± 2 % reading	Range 3 : 1
	Pitot tube	± 2 % reading	Range 3 : 1 local flow only
	Gap meter	± 2 % reading	Range 10 : 1
	Common vane-type meter	± 2 % reading	Range 10 : 1
	Vortex-shedding meter	± 1 % reading	Range 10 : 1
	Turbine meter	± 0.25 % reading	Range 10 : 1
Gas analysis	CO colorimetric	± 10 % reading	Range to be selected
	CO_2 Orsat	± 0.1 % CO_2	Delicate, requires expert use
	CO_2 compact absorption type	± 0.3 % CO_2	Simple and robust
	CO_2 katharometer	± 0.2 % CO_2	Can be vitiated by other gases
	O_2 Orsat	± 0.2 % O_2	Delicate, requires expert use
	O_2 compact absorption type	± 0.3 % O_2	Simple and robust
	O_2 paramagnetic	± 0.1 % O_2	Robust, air calibrated
	O_2 electrochemical cell[b]	± 0.2 % O_2	Cell deteriorates in time
Mass	Weighbridge	± 0.5 % reading	Solid and liquid fuels
Pressure	Bourdon gauge	± 2 % full scale deflection	Robust
Temperature	Mercury-in-glass thermometer	± 1 scale division	Delicate
	Mercury-in-steel thermometer	± 1 scale division	Robust, but bulky
	Thermocouple	± 1 °C	Robust and very flexible
	Resistance thermometer	± 0.1 °C	

NOTE The above table should be regarded as a guide since new forms of portable instrument are continually becoming available (e.g. infra-red analysers and electrochemical cells for certain gas analyses) and this should be borne in mind.

[a] After calibrating, where appropriate. Different makes and models of instruments may vary in the manner in which their probable reading errors are expressed.

[b] Where an electro-chemical cell is used convert the result to a dry basis.

5 Procedure

5.1 General

Tests shall be carried out whilst the boiler is fired continuously under steady state conditions established prior to the test (see **5.2**).

NOTE An outline of the procedure for calculating from test measurements is shown in Figure 1.

5.2 Steady state

5.2.1 Steam pressure and feed water temperature or, for hot water boilers, the flow and return temperatures, together with the relevant flow rates, shall be held as steady as possible and at levels close to normal operating conditions.

NOTE 1 For special operating conditions applying in the case of solid fuel combustion devices having a cyclic pattern of operation see **5.5.2.2**.

NOTE 2 During the operation of a boiler the various factors contributing to heat losses will vary from their intended values as a result of the absorption of heat by the boiler structure as it acquires the conditions determined for the test and as a result of the operation of automatic controls. The most important variables are the exit gas temperature and the CO_2 or O_2 content of the exit gases. It is therefore essential that tests are conducted only after steady state conditions have been achieved.

It should be borne in mind that:

a) a rise of 1 K in heat carrier temperature will cause the exit gas temperature to rise by about 0.75 K;

b) at typical CO_2 or O_2 levels a rise of 17 K in exit gas temperature will cause an increase in dry gas loss of about one percentage point;

c) at typical exit gas temperatures an increase in CO_2, or decrease in O_2, of 0.5 % will decrease the dry gas loss by about one percentage point.

For further information see Appendix B.

5.2.2 For the purposes of this standard, steady state conditions shall be deemed to have been reached, for solid fuel fired boilers with continuous fuel and ash flows and for liquid and gaseous fuel fired boilers, when over a period of 1 h immediately before the test, drift in exit gas temperature does not exceed ± 10 K/h from the mean value.

NOTE For solid fuel combustion devices having a cyclic pattern of operation see **5.5.2.2**.

5.3 Test preparations

5.3.1 It shall be confirmed that the water treatment is being carried out according to the instructions of the boilermaker and the supplier of the water treatment plant. Where necessary during the preliminary running of the boiler prior to the test, except when testing under "as found" conditions (see **5.3.2**), the gas side surfaces shall be cleaned, the fuel input and fuel air ratio shall be set and adjustment of the combustion chamber draught or pressure shall be made to conditions laid down by the boilermakers before establishing steady state conditions.

The boiler and firing equipment shall be inspected for gas tightness, i.e. flue-gas leakage on positive pressure systems or air infiltration on negative pressure systems. Any defects shall be rectified before establishing steady state conditions.

5.3.2 When testing under "as found" conditions, e.g. whenever the user wishes to determine the current performance of the plant, no adjustments to the firing equipment shall be made and no cleaning of the gas-side surfaces shall be carried out prior to the commencement of the test.

NOTE Factors relating to maladjustment of the firing equipment, grit and dust emission, fouled heat transfer surfaces or the formation of CO will be shown up by such tests and will be a guide to improvements in operation, which should be confirmed by retest. A comparison with the manufacturer's performance data should be made.

5.4 Requirements during test

During the running of the test the blowdown of steam boilers shall be avoided and the water level in the gauge glasses shall be held as steady as possible during the establishment of steady state conditions and during the subsequent test.

Where automatic high/low or fully modulating firing equipment is fitted no manual adjustment of combustion settings during the overall test period shall be carried out (see **3.2**).

5.5 Duration of tests

5.5.1 *Oil and gas fired boilers.* Following the establishment of the steady state the test shall be of sufficient duration for at least six complete sets of readings of fuel input or heat output rate, flue gas temperature and flue gas analysis to be carried out at 10 min intervals. The readings shall be within the variations permitted by the strict terms of steady state conditions (see **5.2**).

NOTE A minimum test period of one hour is recommended.

5.5.2 *Solid fuel fired boilers*

5.5.2.1 For solid fuel combustion appliances having continuous fuel and ash flows (e.g. chain-grate, reciprocating grate or sprinkler/spreader stokers), a test shall last not less than 2 h.

5.5.2.2 For solid fuel combustion devices having a cyclic pattern due to periodic refuelling and/or de-ashing, e.g. hand firing, underfeed and some types of overfeed stokers, and which cannot be operated at the same steady state conditions as those boilers referred to in **5.2.2**, the test period shall be that period between consecutive de-ashing operations at which fire bed conditions are as constant as possible. The special test procedure is given in **5.9**.

5.6 Combustibles in ash, riddlings and grit from solid fuel fired boilers

The combustible residues produced during the test period shall be collected, weighed and sampled for analysis in accordance with BS 1016-14. On removal from the ash pit the ashes shall be weighed without delay and then quenched with water to avoid continued combustion of unburnt fuel. Samples shall be analysed in accordance with BS 1016-14 and the results shall be corrected to a dry basis.

Where a grit arrestor is fitted the grit shall be weighed and sampled for analysis.

5.7 Combustibles in flue gases

The CO content, under the conditions of the test, shall be measured and if below 0.1 % it may be ignored thereafter. Above this limit the CO content shall be measured during the test (see **5.8.2**) and taken into account in the calculations.

5.8 Procedure for the determination of exit gas temperature and CO, CO_2 or O_2 content

NOTE Further information concerning the sampling and analysis of flue gases is given in BS 1756 and BS 3048.

5.8.1 The exit gas temperature shall be measured by using a probe comprising a fine wire thermocouple with the tip left bare (see BS 4937-20) supported in a small bore tube, in conjunction with a digital indicator, or by using one of the alternative instruments given in Table 1, compensating where necessary for the cold junction.

NOTE A fine wire thermocouple used in conjunction with a digital indicator responds rapidly to changes in temperature. A chart recorder may be used to show the peaks in exit gas temperature but the digital indicator can be used also for this purpose if an observer is employed to plot temperature and time.

5.8.2 For measurement of exit gas CO, CO_2 and O_2 content, a hole shall be provided, as near as practicable to the final heat transfer surfaces of the boiler, in the ducting or boiler casing, as appropriate, the diameter being just large enough to accommodate a gas sampling probe. Any gap shall be sealed against air ingress.

NOTE It is desirable to lag the gas exit duct with approximately 50 mm of rock wool from the boiler outlet to approximately one duct diameter downstream of the hole.

5.8.3 The gas sampling probe shall be located in close proximity to the temperature sensor in order to avoid errors.

NOTE It is advantageous to use a combined temperature sensor support tube and gas sampling probe.

5.8.4 The probes for both temperature measurement and gas sampling shall be of sufficient length to traverse the duct. Prior to the test period readings shall be taken at the centre of the cross section of the duct and at a minimum of four other representative points and then averaged.

NOTE If it is found that a single position gives readings representative of the average, this position may be used for subsequent observations provided that the firing conditions remain unaltered.

5.8.5 When testing gas fired boilers fitted with or incorporating down-draught diverters, the flue gas samples shall be taken from, and the temperatures shall be measured at, positions at which the analyses and temperatures are not affected by the ingress of diluting air.

5.9 Procedure for testing solid fuel combustion appliances having a cyclic pattern

Measurements of exit gas temperature and CO_2 (or O_2) content of the flue gases shall be made throughout the test period at regular intervals of not more than 10 min. The total mass of fuel consumed during, and of ash removed at the end of, the test period shall be measured.

The average total flue gas loss shall be calculated and this shall be used, in conjunction with the other losses, to determine the average efficiency. The total fuel consumed shall be used, in conjunction with the efficiency, to calculate the average output obtained under the particular conditions applying during the test, excluding the actual de-ashing period. The performance shall be declared on this basis.

NOTE If required the test may be repeated at different manually held firing rates.

5.10 Undetermined losses

Undetermined losses, i.e. losses which are neither measured nor assessed, may occur but shall be regarded as insignificant for the purposes of this Part of BS 845.

6 Calculations

NOTE For a summary of the symbols and their units used in this clause see Table 2.

6.1 General

The calculations necessary to complete the assessment of thermal performance shall be in accordance with the equations given in **6.2** to **6.6**.

The equations provide for calculations on a basis of either the gross (subscript "gr") or the net (subscript "net") calorific value of the fuel; whichever value is used the basis shall be stated in the test report [see Appendix A k)].

NOTE 1 An outline of the procedure for calculation from test measurements is shown in Figure 1.

NOTE 2 The data required to complete the calculations are fully itemised in the test report (see Appendix A), which includes a tabulation of the heat account [see Appendix A k)].

6.2 Calculation of the heat supplied by the fuel, Q_i, where the heat input is measured

6.2.1 *Heat supplied by solid fuels*

$$Q_{i\,gr} = \frac{M_f\,Q_{gr}}{T} \tag{1}$$

$$Q_{i\,net} = \frac{M_f\,Q_{net}}{T} \tag{2}$$

6.2.2 *Heat supplied by liquid fuels*

$$Q_{i\,gr} = \frac{M_f}{T}\left[Q_{gr} + 1.92\,(t_f - t_a)\right] \tag{3}$$

$$Q_{i\,net} = \frac{M_f}{T}\left[Q_{net} + 1.92\,(t_f - t_a)\right] \tag{4}$$

6.2.3 *Heat supplied by gaseous fuels*

$$Q_{i\,gr} = 1\,000\,V\,Q_{gr} \tag{5}$$

$$Q_{i\,net} = 1\,000\,V\,Q_{net} \tag{6}$$

NOTE $V = \dfrac{V_m\,(P_a + P_g)\,288}{1013(t_g + 273)}$

6.3 Calculation of the losses

6.3.1 *Loss due to sensible heat in dry flue gases, L_1*

$$L_{1\,gr} = \frac{k_{gr}(t_3 - t_a)\left[1 - 0.01\,(L_{4\,gr} + L_{5\,gr})\right]}{V_{CO_2}} \tag{7}$$

$$L_{1\,net} = \frac{k_{net}(t_3 - t_a)\left[1 - 0.01\,(L_{4net} + L_{5net})\right]}{V_{CO_2}} \tag{8}$$

NOTE 1 L_4 and L_5 are applicable to solid fuel only and formulae are given in **6.3.4** and **6.3.5** respectively.

NOTE 2 k is the Siegert constant, and its value for any carbon-containing fuel is given by the following:

$$k_{gr} = \frac{255C}{Q_{gr}}$$

or

$$k_{net} = \frac{255C}{Q_{net}}$$

where

C is the carbon content of the fuel on the same basis as Q

For all fuels Q_{gr}, Q_{net} and C are on the mass basis.

Typical values of k for common fuels are:

Fuel	k_{gr}	k_{net}
Coke	0.75	0.76
Anthracite	0.67	0.69
Coal	0.62	0.65
Fuel oil, BS 2869, classes E, F, G	0.51	0.54
Fuel oil, BS 2869, class D	0.48	0.51
LPG, butane	0.43	0.46
LPG, propane	0.42	0.45
Natural gas	0.35	0.39

Values for C and Q should be obtained from the fuel supplier or, if not available from this source, reference should be made to "Technical Data on Fuel" 7th ed. by J W Rose and J R Cooper. Ch. "Fuels", published by the British National Committee of the World Energy Conference, 34 St James's Street, London SW1A 11HD.

NOTE 3 If O_2 rather than CO_2 is measured, then the volume of CO_2 is given by:

$$\left(1 - \frac{V_{O_2}}{21}\right)\frac{V}{CO_2} \tag{9}$$

where

$\dfrac{V}{CO_2}$ is the stoichiometric volume of CO_2

Typical values of $\dfrac{V}{CO_2}$ for common fuels are:

Fuel	Stoichiometric volume of CO_2, $\frac{V}{CO_2}$ (per cent dry basis)
Coke	20.6
Anthracite	19.1
Coal	18.4
Fuel oil, BS 2869, classes E, F, G	15.8
Fuel oil, BS 2869, class D	15.5
LPG, butane	14.1
LPG, propane	13.8
Natural gas	11.9

6.3.2 ***Losses due to enthalpy in the water vapour in the flue gases,*** L_2

$$L_{2\ \mathrm{gr}} = \frac{(m_{\mathrm{H_2O}} + 9H)\,(2488 - 4.2t_\mathrm{a} + 2.1t_3)}{Q_\mathrm{gr}} \quad (10)$$

$$L_{2\ \mathrm{net}} = \frac{(m_{\mathrm{H_2O}} + 9H)\,(210 - 4.2t_\mathrm{a} + 2.1t_3)}{Q_\mathrm{net}} \quad (11)$$

NOTE 1 The humidity of the air can normally be neglected in cold or temperate climates, but in hot, moist areas, or where steam is added to the combustion air (e.g. for cooling grate bars), increase L_2 by X which is given by

$$X_\mathrm{gr} = \frac{1.88\,w\,\overline{W}\left(1 + \frac{a_3}{100}\right)(t_3 - t_\mathrm{a})}{Q_\mathrm{gr}}$$

$$X_\mathrm{net} = \frac{1.88\,w\,\overline{W}\left(1 + \frac{a_3}{100}\right)(t_3 - t_\mathrm{a})}{Q_\mathrm{net}}$$

where

t_a is the ordinary dry bulb air temperature.

To establish the value of w measure also the wet bulb temperature.

Values of w can be obtained from Table **4.46** in "Technical Data on Fuel" 7th ed. by J W Rose and J R Cooper, published by the British National Committee of the World Energy Conference, 34 St James's Street, London SW1A 11HD.

Values of $\overline{W}$ can be obtained from the same publication, Tables 5.15 (gases), 5.25 (oils), and 5.44 (coal). These tables give typical values, reference should be made to the supplier for more precise figures.

a_3 may be calculated from:

$$a_3 = \frac{9.5\,V_{\mathrm{O_2}}}{21 - V_{\mathrm{O_2}}}$$

NOTE 2 The calorific values of gaseous fuels are usually presented as MJ/m^3. The values required in equations 10 and 11 must be in kJ/kgm which can be simply obtained by multiplying MJ/m^3 by 1 000 and dividing by the density of the gas in kg/m^3. For North Sea Gas the density is approximately 0.732 kg/m^3, for commercial propane it is approximately 1.869 kg/m^3, and for commercial butane it is approximately 2.383 kg/m^3, all at 1 013 mbar[2)] and 15 °C.

NOTE 3 In the absence of fuel analyses typical values of the hydrogen content of fuel, H, may be used in equations 10 and 11 as follows:

Fuel	Hydrogen content of fuel *H* (as fired)
Coke	0.4
Anthracite	3.0
Coal	4.0
Fuel oil, BS 2869, classes E, F, G	11.5
Fuel oil, BS 2869, class D	13.0
LPG, butane	17.2
LPG, propane	18.2
Natural gas	24.4

6.3.3 ***Loss due to unburned gases in the flue gases,*** L_3

$$L_{3\ \mathrm{gr}} = \frac{K_1 V_\mathrm{CO}\,[l - 0.01\,(L_{4\ \mathrm{gr}} + L_{5\ \mathrm{gr}})]}{V_{\mathrm{CO_2}} + V_\mathrm{CO}} \quad (12)$$

$$L_{3\ \mathrm{net}} = \frac{L_{3\ \mathrm{gr}}\,Q_\mathrm{gr}}{Q_\mathrm{net}} \quad (13)$$

NOTE Values of the constant k_1 in equation 12 may be taken as follows:

Fuel	Constant k_1
Coke	70
Anthracite	65
Coal	63
Fuel oil, BS 2869, classes E, F, G	54
Fuel oil, BS 2869, class D	53
LPG, butane	48
LPG, propane	48
Natural gas	40

6.3.4 ***Loss due to combustible matter in ash and riddlings,*** L_4

$$L_{4\ \mathrm{gr}} = \frac{33820\ M_1 a_1}{M_\mathrm{f}\,Q_\mathrm{gr}} \quad (14)$$

$$L_{4\ \mathrm{net}} = \frac{L_{4\ \mathrm{gr}}\,Q_\mathrm{gr}}{Q_\mathrm{net}} \quad (15)$$

6.3.5 ***Loss due to combustible matter in grit and dust,*** L_5

$$L_{5\ \mathrm{gr}} = \frac{33820\ M_2 a_2}{M_\mathrm{f}\,Q_\mathrm{gr}} \quad (16)$$

$$L_{5\ \mathrm{net}} = \frac{L_{5\ \mathrm{gr}}\,Q_{\mathrm{i\ gr}}}{Q_{\mathrm{i\ net}}} \quad (17)$$

6.3.6 ***Radiation, convection and conduction losses,*** L_6

NOTE 1 See also Appendix C.

$$L_{6\ \mathrm{gr}} = \frac{6.7\,A_1(t_\mathrm{k} - t_1)}{Q_{\mathrm{a\ gr}}\,l_1} + \frac{53A_2\,Q_{\mathrm{a\ gr}}}{A\,Q_{\mathrm{R\ gr}}(l_2 + 1.3)} \quad (18)$$

$$L_{6\ \mathrm{net}} = \frac{6.7\,A_1(t_\mathrm{k} - t_1)}{Q_{\mathrm{a\ net}}\,l_1} + \frac{53A_2\,Q_{\mathrm{a\ net}}}{A\,Q_{\mathrm{R\ net}}(l_2 + 1.3)} \quad (19)$$

NOTE 2 If insulation other than material having a thermal conductivity of 0.05 W/(m^2·K) is used, the insulation thicknesses l_1 and l_2 should be multiplied by a factor of 0.05/λ where λ is the thermal conductivity.

2) 1 mbar = 100 N/m^2 = 100 Pa.

6.3.7 ***Total losses, L_t***

$$L_{t\,gr} = (L_1 + L_2 + L_3 + L_4 + L_5 + L_6)_{gr} \quad (20)$$

$$L_{t\,net} = (L_1 + L_2 + L_3 + L_4 + L_5 + L_6)_{net} \quad (21)$$

6.4 Calculation of the thermal efficiency, *E*

$$E_{gr} = 100 - L_{t\,gr} \quad (22)$$

$$E_{net} = 100 - L_{t\,net} \quad (23)$$

6.5 Calculation of the heat output to the heat carrier Q_c, where the heat input is determined

$$Q_c = \frac{E_{gr}\,Q_{i\,gr}}{100} \quad (24)$$

$$Q_c = \frac{E_{net}\,Q_{i\,net}}{100} \quad (25)$$

6.6 Calculation of the heat output to the heat carrier, Q_c, where the flowrate to the heat carrier is measured

6.6.1 ***Hot water boilers***

$$Q_c = F_1\,c\,(t_4 - t_5) \quad (26)$$

6.6.2 ***Steam boilers***

$$Q_c = F_2\,[(h + qS) - (t_5\,c)] \quad (27)$$

7 Report

The report shall include the data set out in Appendix A.

Table 2 — Symbols and units

Symbol	Definition	Unit
A	Total external surface area of boiler = $A_1 + A_2$	m^2
A_1	Water or steam backed external surface area of boiler	m^2
A_2	Gas-backed external surface area of boiler	m^2
a_1	Carbon content of ashes and riddlings, dry basis	%
a_2	Carbon content of grit and dust, dry basis	%
a_3	Combustion excess air	%
C	Carbon content of fuel as fired	%
c	Specific heat capacity of heat carrier (water = 4.1868)[a]	kJ/(kg·K)
E_{gr}	Thermal efficiency (based on gross calorific value)	%
E_{net}	Thermal efficiency (based on net calorific value)	%
F_1	Flow rate of water leaving boiler[a]	kg/s
F_2	Flow rate of steam leaving boiler or feed water[a] entering boiler	kg/s
H	Hydrogen content of fuel as fired	%
h	Sensible heat of steam at the pressure of steam[a] discharged from the boiler (taken from steam tables)	kJ/kg
k_{gr}	Constant (Siegert) in equation 7 (based on gross calorific value)	—
k_{net}	Constant (Siegert) in equation 8 (based on net calorific value)	—
k_1	Constant in equation 12	—
$L_{1\ gr}$	Loss due to sensible heat in dry flue gases (based on gross calorific value)	%
$L_{1\ net}$	Loss due to sensible heat in dry flue gases (based on net calorific value)	%
$L_{2\ gr}$	Loss due to enthalpy in water vapour (based on gross calorific value)	%
$L_{2\ net}$	Loss due to enthalpy in water vapour (based on net calorific value)	%
$L_{3\ gr}$	Loss due to unburned gases (based on gross calorific value)	%
$L_{3\ net}$	Loss due to unburned gases (based on net calorific value)	%
$L_{4\ gr}$	Loss due to combustible matter in ashes and riddlings (based on gross calorific value)	%
$L_{4\ net}$	Loss due to combustible matter in ashes and riddlings (based on net calorific value)	%
$L_{5\ gr}$	Loss due to combustible matter in dust and grit (based on gross calorific value)	%
$L_{5\ net}$	Loss due to combustible matter in dust and grit (based on net calorific value)	%
$L_{6\ gr}$	Loss due to radiation, convection and conduction (based on gross calorific value)	%
$L_{6\ net}$	Loss due to radiation, convection and conduction (based on net calorific value)	%
$L_{t\ gr}$	Total losses (based on gross calorific value)	%
$L_{t\ net}$	Total losses (based on net calorific value)	%
l_1	Thickness of insulation having a thermal conductivity of 0.05 W/(m^2·K) on water or steam backed surfaces	mm
l_2	Thickness of insulation having a thermal conductivity of 0.05 W/(m^2·K) on gas-backed surfaces	mm
M_f	Quantity of fuel burned in time T	kg

[a] If the heat carrier is other than the steam/water substance (e.g. a proprietary hydrocarbon oil or synthetic fluid) the relevant thermodynamic data should be obtained from the supplier.

Table 2 — Symbols and units

Symbol	Definition	Unit
M_1	Quantity of ashes and riddlings collected in time T (dry basis)	kg
M_2	Quantity of dust and grit collected in time T (dry basis)	kg
m_{H_2O}	Moisture content of fuel as fired	%
p_a	Atmospheric pressure	m bar
p_g	Pressure of gas supply measured at meter	m bar
Q_{gr}	Gross calorific value of fuel at constant pressure (For gaseous fuels the standard condition is 15 °C and 1013.25 mbar)	kJ/kg (MJ/m^3)
Q_{net}	Net calorific value of fuel at constant pressure (For gaseous fuels the standard condition is 15 °C and 1013.25 mbar)	kJ/kg (MJ/m^3)
$Q_{i\ gr}$	Rate of heat supply by fuel (based on gross calorific value)	kW
$Q_{i\ net}$	Rate of heat supply by fuel (based on net calorific value)	kW
$Q_{R\ gr}$	Rate of heat input at rated output of boiler based on gross calorific value of fuel	kW
$Q_{R\ net}$	Rate of heat input at rated output of boiler based on net calorific value of fuel	kW
$Q_{a\ gr}$	Actual rate of heat input to boiler during test based on gross calorific value of fuel	kW
$Q_{a\ net}$	Actual rate of heat input to boiler during test based on net calorific value of fuel	kW
Q_c	Output to heat carrier	kW
q	Dryness fraction of wet steam determined in accordance with BS 3812	%
S	Latent heat of steam at pressure of steam discharged from the boiler (taken from steam tables)	kJ/kg
T	Duration of test	s
t_1	Ambient temperature	°C
t_3	Temperature of gases leaving boiler	°C
t_4	Temperature of water leaving boiler	°C
t_5	Temperature of water entering boiler	°C
t_a	Temperature of air entering combustion system	°C
t_f	Temperature of liquid fuel at atomizer	°C
t_g	Temperature of gaseous fuel at meter	°C
t_k	Heat carrier flow temperature	°C
V_m	Flow rate of gaseous fuel as measured	m^3/s
V	Flow rate of gaseous fuel corrected to standard conditions	m^3/s
V_{CO_2}	Volume of CO_2 in gases leaving boiler, dry basis	%
V_{O_2}	Volume of O_2 in gases leaving boiler, dry basis	%
V_{CO}	Volume of CO in gases leaving boiler, dry basis	%
$\frac{V}{CO_2}$	Stoichiometric volume of CO_2 dry basis	%
w	Specific humidity of the combustion air	kg/kg
$\overline{W}$	Stoichiometric air for the fuel	kg/kg

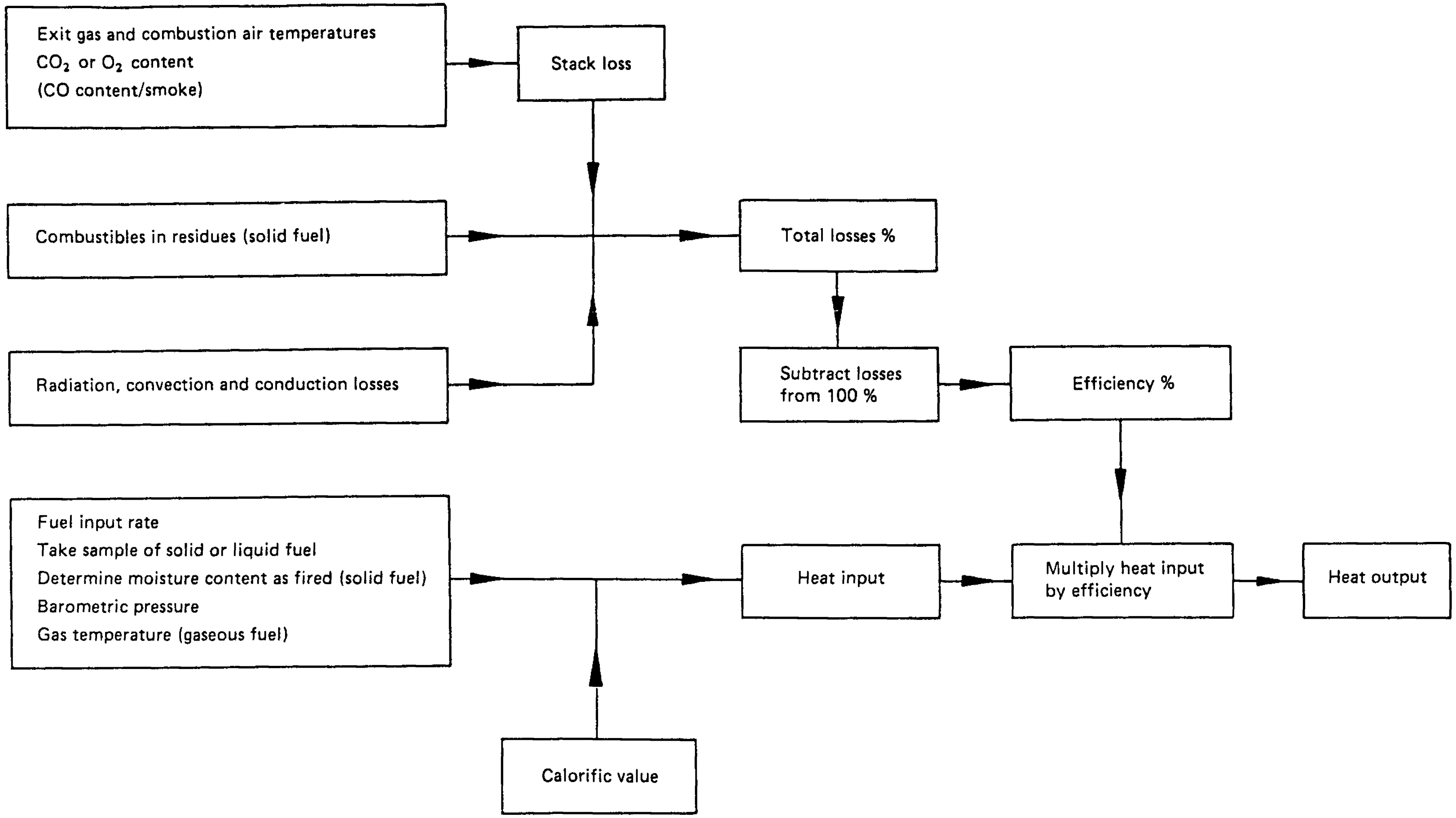

Figure 1 — Outline of the procedure for calculating from the test measurements

Appendix A Report data

NOTE The data shown are the minima required to carry out the thermal performance assessment. They may be supplemented by further details of plant and fuel.

a) The name and address of the premises.

b) The boiler house designation.

c) The name, title and affiliation of the assessment supervisor.

d) The name, title and affiliation of the witness to the assessment.

e) The following boiler data:

1) maker;

2) maker's number;

3) number of boilers in boiler house;

4) boiler number as designated in boiler house;

5) type and description;

6) maximum rated output (in kW);

7) working gauge pressure (in bar);

8) final steam temperature (in °C);

9) feed temperature of steam boiler (in °C);

10) flow temperatures of hot water boilers (in °C);

11) return temperatures of hot water boilers (in °C).

f) The following firing equipment data:

1) burner/stoker manufacturer;

2) type of burner/stoker;

3) turn-down ratio of burner/stoker.

g) The following fuel-data:

1) type;

2) description and characteristics of solid fuel;

3) gross calorific value, Q_{gr} (in kJ/kg or MJ/m^3);

4) net calorific value, Q_{net} (in kJ/kg or MJ/m^3);

5) carbon content of liquid and solid fuel, C (%);

6) hydrogen content of liquid and solid fuel, H (%).

h) The following data for the heat carrier (if the heat carrier is other than the steam/water substance):

1) name or designation of the fluid;

2) thermodynamic information for the conditions of the test.

i) The test data as listed in the following table.

Measurement	Unit	Firing rate		
		High	Medium	Low
Duration of test, T	s			
Temperature of combustion air, t_a	°C			
Temperature of gases leaving boiler, t_3	°C			
Volume % of CO_2 in gases leaving boiler, V_{CO_2}	%			
Volume % of O_2 in gases leaving boiler, V_{O_2}	%			
Volume % of CO in gases leaving boiler, V_{CO}	%			
Bacharach or Ringelmann number (see BS 2742)				
Solid or liquid fuel fired, M_f	kg			
Gas fuel fired	mm^3			
Ashes and riddlings collected, dry basis, M_1	kg			
Grit and dust collected, M_2	kg			

NOTE The above measurements (or the mean of repeated measurements) are to be obtained after steady state conditions at each firing rate have been achieved in accordance with **5.2**.

j) The test observations as listed in the following table.

Item	Unit	Firing rate		
		High	Medium	Low
Mean gauge pressure of steam in boiler	bar			
Mean temperature of steam or flow water	°C			
Mean temperature of feed or return water	°C			
Moisture content of fuel, m_{H_2O}	%			
Carbon content of ashes and riddlings, a_1	%			
Carbon content of grit and dust, a_2	%			
Atmospheric pressure, p_a	mbar			
Pressure of gas at meter, p_g	mbar			
Temperature of gas at meter, t_g	°C			
Temperature of liquid fuel at burner, t_f	°C			

k) Data to complete the following heat account (based on either gross or net calorific value: state which).

Description of loss	Unit	Firing rate		
		High	Medium	Low
Loss due to dry flue gases, L_1	%			
Loss due to enthalpy in water vapour, L_2	%			
Loss due to unburned gases in flue gases, L_3	%			
Loss due to unburned carbon in ashes and riddlings, L_4	%			
Loss due to unburned carbon in grit and dust, L_5	%			
Radiation, convection and conduction losses, L_6	%			
Total losses, L_t	%			
Thermal efficiency, E	%			
Estimated error[a] ± percentage points	%			
[a] See **B.2**.				

l) The following deductions.

Description of loss	Unit	Firing rate		
		High	Medium	Low
Output to heat carrier, Q_c	kW			
Probable error[a] ± percentage points	%			
Percentage of boiler rating	%			
[a] See **B.3**.				

m) The following details for certification purposes:

1) Assessment carried out on (date) ....

2) Assessment carried out by ....
representing ....

3) Assessment witnessed by ....
representing ....

Appendix B The accuracy of boiler tests

B.1 Introduction

It is important to know the accuracy with which a boiler test has been conducted. There are instrument errors which are given in Table 1, sampling errors for which allowance can be made, and human errors for which allowance cannot be made. Considering the first two factors only, it is the purpose of this appendix to show how the results of boiler tests are affected by errors which are known or can be estimated and to indicate how the maximum error range for a boiler test can be calculated using a simple procedure. It is emphasized that the result of the calculation will give the maximum possible error; the actual error will be less than this.

B.2 Errors in the determination of losses and efficiency

B.2.1 *The dry gas loss* L_1 *(equation 7 or 8)*

This is the most variable and important loss given generally by the following:

$$L_1 = \frac{k(t_3 - t_a)[l - 0.01(L_4 + L_5)]}{V_{CO_2}}$$

$L_4 + L_5$ are the losses due to incomplete combustion. Their effect, if present (normally only with solid fuel firing), is to reduce L_1 and the quantity involved is small. The equation, for the purpose of this discussion, can therefore be simplified to the following:

$$L_1 = \frac{k(t_3 - t_a)}{V_{CO_2}}$$

If e_t is the measurement error in $(t_3 - t_a)$ and e_{CO_2} is the measurement error in V_{CO_2} the new value of L_1 will be given by the following:

$$L_1' = \frac{k(t_3 - t_a + e_t)}{V_{CO_2} - e_{CO_2}}$$

NOTE The superscript $'$ is used to indicate the value of a loss when errors are included and will be used as such throughout this appendix.

Dividing:

$$\frac{L_1'}{L_1} = \frac{t_3 - t_a + e_t}{t_3 - t_a} \; \frac{V_{CO_2}}{(V_{CO_2} - e_{CO_2})} \qquad (28)$$

The value of e_t is expressed in kelvin. The error in t_3 is given in Table 1 and where relevant converted to degrees; the error in t_a is given in degrees and can be used directly. The two errors are added to give e_t. The value of e_{CO} is also given in Table 1; if oxygen is measured the error value given in Table 1 is equally valid for CO_2 derived from equation 9; e_{CO_2} is in terms of percentage CO_2.

B.2.2 *Enthalpy in water vapour* L_2 *(equation 10 or 11)*

This is not very variable; the errors are likely to be in the measurements of calorific value, hydrogen content of the fuel, t_3 and t_a. The greatest error likely to occur from these sources combined is below 0.1 percentage points. It will therefore be sufficient to add 0.1 percentage points to the calculated value of L_2 as follows:

$$L_2' = L_2 + 0.1 \qquad (29)$$

B.2.3 *Losses due to incomplete combustion* L_3, L_4, L_5 *(equations 12 or 13, 14 or 15, 16 or 17)*

Sampling is involved and this will be the main source of error. A generous allowance of 25 % is as follows:

$$(L_3' + L_4' + L_5') = 1.25\,(L_3 + L_4 + L_5) \qquad (30)$$

B.2.4 ***Radiation, convection and conduction losses*** L_6 *(equations 18 or 19)*

These are assessed losses and there will be errors due to assumptions made and to changes in environmental conditions. Again an allowance of 25 % is made as follows:

$$L_6' = 1.25\ L_6 \tag{31}$$

B.2.5 ***Overall error***

The total loss L_t is given by equation 20 or equation 21:

$$L_t = (L_1 + L_2 + L_3 + L_4 + L_5 + L_6)$$

Likewise

$$L_t' = (L_1' + L_2' + L_3' + L_4' + L_5' + L_6') \tag{32}$$

$L_t' - L_t$ is the sum of the loss errors and will be a plus or minus error; it should be prefixed by the sign ±.

It is emphasized that the result of the calculation will give the maximum possible error; the actual error will be less than this.

B.2.6 ***Summary of method of calculation of error band***

a) Evaluate the losses in accordance with clause **6**.

b) From Table 1, or alternative source, decide on the accuracy limits of the instruments used to measure t_3, t_a and CO_2 (or O_2).

c) Using equation 7 or 8 calculate L_1. Using equation 28 calculate L_1'.

d) Using equation 10 or 11 calculate L_2. Using equation 29 calculate L_2'.

e) Using equations 12 or 13, 14 or 15, and 16 or 17 calculate $L_3 + L_4 + L_5$. Using equation 30 calculate $L_3' + L_4' + L_5'$.

f) Using Appendix B or equations 18 or 19 assess L_6. Using equation 31 calculate L_6'.

g) Using equation 20 or 21 calculate L_t. Using equation 32 calculate L_t'.

h) Deduct L_t from L_t' to give the overall error in loss (and efficiency) measurement. This is in percentage points and, prefixed by the sign ±, should be included in the report.

B.3 Errors in determination of boiler output

B.3.1 The boiler output is given by equations 24 or 25:

$$Q_c = \frac{E\ Q_i}{100}$$

The error in E has been evaluated in **A.2.6** h) but there are errors in determining Q_i. These include those associated with the measurement of mass or volume flow of the fuel (see Table 1), the determination of calorific value, and the measurement of time.

From equation 1 or 2:

$$Q_i = \frac{M_f\,Q}{T}$$

$$Q_i' = \frac{(M_f + e_{M_f})\ (Q + e_Q)}{T - e_T} \tag{33}$$

Where e_{M_f}, e_Q and e_T are the errors in measurement of M_f, Q and T respectively.

Neglecting e_T:

$$\frac{Q_i'}{Q_i} = \frac{(M_f + e_{M_f})}{M_f}\ \frac{(Q + e_Q)}{Q}$$

B.3.2 To obtain the error band in output therefore:

a) Calculate E and E' from **B.2.6** h) and equation 22 or 23.

b) Calculate Q_i from equation 1 or 2 and Q_i' from equation 33.

c) Calculate Q_c and Q_c' from the following:

$$Q_c = \frac{E\,Q_i}{100}$$

$$Q_c' = \frac{E'Q_i'}{100}$$

d) Evaluate $Q_c' - Q_c$ and divide by $\frac{Q_c}{100}$ to give percentage error in output measurement, which will be a plus or minus error.

Appendix C Radiation, convection and conduction losses for boilers of conventional design

The radiation, convection and conduction losses from a boiler depend upon its design and construction and are small as a proportion of the total losses. Experience has shown that the radiation, convection and conduction losses in the case of conventional designs consistently fall within ranges for the various types of boiler.

Characteristics of common types of boiler are shown in Table 3 and Table 4 together with typical radiation, convection and conduction losses at rated output. Where the type of boiler can generally be recognized but one characteristic varies from that shown in the tables, the relevant losses may be interpolated. However, where the type cannot readily be recognized, the losses should be calculated as given in **6.3.6**.

The percentage radiation, convection and conduction losses at outputs other than the rated output can be assumed to be in inverse proportion to the ratio of the actual fuel input to the fuel input at the rated output.

Table 3 — Typical radiation, convection and conduction losses from water-tube and shell boilers

Boiler type	Design details	Total loss[a] at rated output based on gross calorific value %
A	Water-tube and multitubular shell boilers with rated outputs of 5 MW and above	0.3
B	Water-tube and multitubular shell boilers with rated outputs of 2 MW and above but less than 5 MW	0.5
C	Water-tube and multitubular shell boilers with rated outputs below 2 MW	1.0
D	Brickset and dry back multitubular and brickhearth boilers	1.5
E	Brickset water-tube boilers with water walls	2.0
F	Brickset water-tube boilers without water walls	2.5
G	Brickset Lancashire and Cornish boilers	4.0

[a] Radiation, convection and conduction losses are combined to give the total loss as a percentage of the heat input, under stable test conditions and at the rated output.

Table 4 — Typical radiation, convection and conduction losses from sectional hot water boilers

Boiler type	Direct openings from combustion chamber	Water cooled base	Closing and clean-out plates and other non-water-backed surface	Insulation	Total loss[a] at rated output based on gross calorific value %
A	None	Yes	Less than 10 % of total surface	40 mm applied directly to the boiler surface	1.5
B	Less than 2 000 mm^2/kW	No but not exceeding 120 °C	Less than 10 % of total surface	40 mm applied directly to the boiler surface	3
C	Less than 2 000 mm^2/kW	No but not exceeding 9 000 mm^2/kW	Less than 10 % of total surface	25 mm within casing	4

[a] Radiation, convection and conduction losses are combined to give the total loss as a percentage of the heat input, under stable test conditions and at the rated output.

Publications referred to

BS 526, *Definitions of the calorific value of fuels.*
BS 1016, *Methods for analysis and testing of coal and coke.*
BS 1016-14, *Analysis of coal ash and coke ash.*
BS 1756, *Methods for sampling and analysis of flue gases.*
BS 2742, *Notes on the use of the Ringelmann and miniature smoke charts.*
BS 2869, *Specification for fuel oils for oil engines and burners for non-marine use.*
BS 3048, *Code for the continuous sampling and automatic analysis of flue gases: indicators and recorders.*
BS 3812, *Recommendations for estimating the dryness of saturated steam.*
BS 4937, *International thermocouple reference tables.*
BS 4937-20, *Specification for thermocouple tolerances.*

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