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Regular inspection of boilers - Simple on-site measurements for estimating energy performance

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This information paper intends to explain to non-specialists how to estimate the energy efficiency of a boiler from only few measurements.

1 > Regular inspection of boilers: what is required?

The Energy Performance of Buildings Directive *[1]* introduces regular inspection of boilers considering that:

> *[…] regular maintenance of boilers […] by qualified personnel contributes to maintaining their correct adjustment in accordance with the product specification and in that way will ensure optimal performance from an environmental, safety and energy point of view.*

According to draft standard prEN 15378 *[2]* about boilers inspection, "regular boiler inspection procedures and methods are intended to:

- verify if the boiler is set, operated and maintained correctly with regard to energy efficiency;
- estimate actual boiler energy performance;
- support advice on possible boiler energy performance improvements."

EN 15378 is under construction in European Standardisation Technical Committee CEN/TC 228

2 > What is the efficiency of a boiler?

A boiler is designed to transmit the heat released from combustion to water.

The quantity of the heat released by combustion depends on the quantity of the heat contained within the fuel, which is the calorific value of the fuel.

The heat released by combustion inside the boiler is usually called **heat input**. It is directly linked to the quantity of fuel which is introduced into the burner.

The combustion of fuel inside the boiler releases hot gases (combustion products) which, together with some heat radiation, warm up the water of the heating system as it flows through the boiler.

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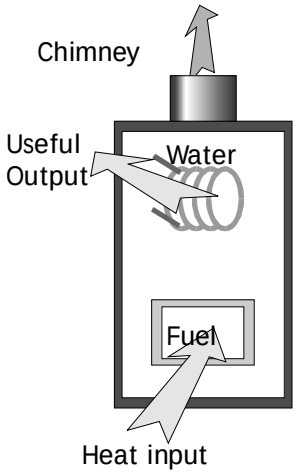
Additionally, in condensing boilers, a part of the water vapour contained in the combustion products transmits heat to the water of the heating system when it condensates inside the boiler.

The heat transmitted to water inside the boiler is usually called **useful output**, as it represents the energy which is useful to the heating system.

Useful efficiency is the quantity referred to by the "boiler efficiency" directive [3].

The **useful efficiency** of a boiler is the part of the heat input that is transmitted to water as useful output. For example, in a boiler with a 90% useful efficiency, 90% of the heat released by combustion (heat input) is transmitted to water (useful output).



Heat input and useful output on a schematic view of a boiler.

3 > How to measure the efficiency of a boiler in a laboratory?

The assessment of the useful efficiency of a boiler is a standard operation in boilers testing laboratories. It requires knowledge of the heat input and useful output.

To assess the **heat input**, the following quantities are measured:
- calorific value of the fuel, depending on its chemical composition,
- fuel consumption by the boiler (or flow rate of fuel at the inlet of the burner).

Fuel calorific value may be expressed in kWh/kg, showing the quantity of energy (kWh) per unit of fuel (kg). Fuel flow rate may be for example expressed in kg/h.

The heat input (in kW) is obtained by multiplying the calorific value of the fuel by the fuel flow rate.

To assess the **useful output**, the following quantities are measured:
- water flow rate though the boiler,
- water temperatures at inlet and outlet of the boiler,
- for condensing boilers, amount of liquid condensates released by the boiler.

These data allow to calculate the heat transmitted to water (useful output in kW). The calculation of the useful output uses the measured data mentioned above but also the heat capacity of water, which is known from tables or handbooks.

The ratio between useful output and heat input is the useful efficiency.

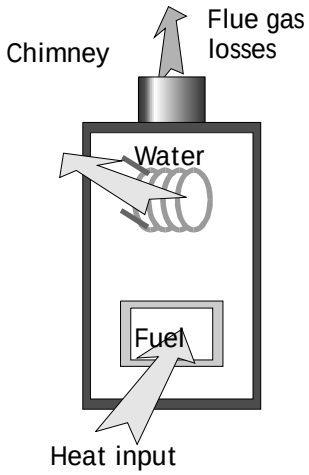
Boiler under test.

4 > How to evaluate the efficiency of a boiler on site?

The assessment of the boiler efficiency on site cannot rely on the measurement of the heat input and useful output: it is generally not possible to measure on site quantities such as fuel calorific value, fuel flow rate, water flow rate,... **Using a simplified approach is therefore necessary.**

In this simplified approach only three quantities are measured:
- the oxygen (or carbon dioxide) content of the flue gases,
- the temperature of combustion products (flue gases) leaving the boiler through the chimney,
- the ambient temperature (in fact the temperature of the air going to be mixed with fuel for combustion).

For condensing boilers, an additional measurement is the quantity of the liquid condensates released by the boiler or, as an alternative, the relative humidity of ambient air and flue gases.



Flue gas losses on a schematic view of a boiler.

These three (or four) rather simple measurements concern only flue gases and ambient air.

They allow to estimate the energy lost by the chimney (**flue gas losses**), and then, with reasonable approximation, the useful efficiency of the boiler as explained below.

They can be performed using portable multifunction measuring appliances such as those covered by standard EN 50379 *[4]*.

Measurements on fuel consumption or water flow of the heating circuit are not required.

5 > Why are three (or four) measurements enough?

The characteristics of the fuel (natural gas, propane, oil, …) used by the boiler are generally known.

A given fuel is characterised by carbon dioxide (CO_2) content of the flue gases (combustion products) in the case of a "perfect" combustion, i. e. with no more and no less air than required for the complete combustion of the fuel.

This carbon dioxide content is a theoretical value which represents a maximum never met in practical cases.

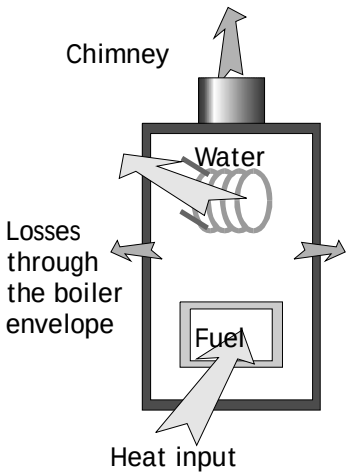
Measuring actual oxygen (or carbon dioxide) content of the flue gases allows to check how far from this maximum theoretical CO_2 content the boiler operates. This enables to estimate the quantity of air which flows through the boiler without being needed by combustion, called **excess air**.

Then, equations that use excess air, ambient temperature and the temperature of flue gases (and the flow rate of liquid condensates, if applicable) make it possible to estimate heat losses through the chimney (flue gas losses in kW).

On site measurements on flue gases and ambient air allow to estimate combustion efficiency.

This gives access to an estimation of the **combustion efficiency**: it is the part of the heat input that is not lost through the chimney. For example, in a boiler with a 92% combustion efficiency, 8% of the heat input is lost through the chimney.

In order to finally get an approximate value of the useful efficiency, another quantity has to be estimated: the heat losses through the boiler envelope.



Losses through the boiler envelope on a schematic view of a boiler.

Although they are insulated, the walls of the boiler casing usually have a temperature somewhere higher than the ambient temperature, leading to some thermal emission. In addition, in some boilers, ambient air may circulate within the boiler envelope and be in contact with warm parts of the boiler, also leading to heat transfer from the boiler to its surroundings.

These **heat losses through the boiler envelope** are very low for recent boilers (much less than 1% of heat input) and can for that reason often be estimated without measurements. In older boilers with less or damaged thermal insulation, they may reach a few % of heat input and can be assessed by measuring the temperature of boiler's envelope walls.

Finally, the useful efficiency (in %) is estimated from these on site measurements by the following calculation:

Subtracting part of heat input lost through boiler envelope from combustion efficiency gives an estimate of useful efficiency.

Useful efficiency	=	*100 -*	*(part of heat input lost through chimney)* -	*(part of heat input lost through envelope)*

For example, a boiler with 9% of the heat input lost through the chimney and 1% of the heat input lost through the boiler envelope will have an estimated useful efficiency of: 100 - 9 - 1 = 90%.

In summary, on site measurements on flue gases and ambient air allow to estimate combustion efficiency. Subtracting the part of the heat input lost through boiler envelope from combustion efficiency gives an estimated value of useful efficiency.

6 > References

1. Directive 2002/91/EC of the European Parliament and of the Council of 16 December 2002 on the energy performance of buildings - Official Journal of the European Communities - 4 January 2003
2. prEN 15378:2005 - Heating systems in buildings - Inspection of boilers and heating systems - European Committee for Standardization - October 2005
3. Council Directive 92/42/EEC of 21 May 1992 on efficiency requirements for new hot-water boilers fired with liquid or gaseous fuels - Official Journal of the European Communities - 22 June 1992
4. EN50379:2004 - Specification for portable electrical apparatus designed to measure combustion flue gas parameters of heating appliances
   Part 1: General requirements and test methods
   Part 2: Performance requirements for apparatus used in statutory inspections and assessment
   Part 3: Performance requirements for apparatus used in non-statutory servicing of gas fired heating appliances

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