[European projects]

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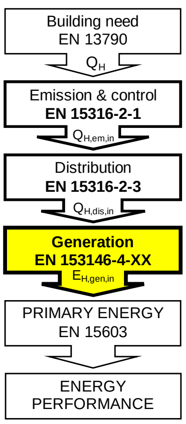

Figure 1: Generation is the 3rd step in the heating system calculation.

Information paper on Space heating generation systems Combustion systems

EN 15316-4-1 (Boiler efficiency).

An efficient combustion system is an interesting and useful solution for reduction of energy consumption in a building. The annual generation efficiency of space heating combustion systems, related to the gross calorific value, varies from about 60% (old boilers) to 95% (condensing boilers).

This paper gives a short introduction to the CEN standard 15316-4-1 to calculate boiler losses, fuel input and auxiliary energy consumption. It contains explanations on the three available calculation methods, with details on the input and output data and the links with the other CEN standards.

The EN standard 15316-4-1 was published in May 2008.

1 > Scope of standard

This standard is part of a series (EN 15316) for the calculation of heating system energy requirements and system efficiencies (see **figure 1**).

This standard gives three calculation methods of the annual energy performance of heat generation for space heating with boilers (combustion systems) using liquid and gaseous fuels, including generator control.

This standard does not cover solid fuel boilers and air heaters which are treated as dedicated parts (EN 15316-4-6 and prEN 15316-4-7 respectively).
Specific parts of EN 15316-4 are dedicated to other generation devices (heat pumps, solar systems, etc.) as well (see **figure 2**).

Boiler sizing is not covered by this standard. This standard is intended to calculate the in-use energy performance of a given boiler, either existing or as designed and sized.

The heat output to be provided by the generator is needed as input data. This is given by the heat input required by the distribution subsystem(s) and calculated according to the distribution part, EN-15316-2-3.

This standard gives little guidance regarding calculation of boiler operating conditions, although these are taken into account in the proposed methods. A separate information paper to be used for all heat generators (heat pumps, cogeneration, etc.) will be provided on this topic.

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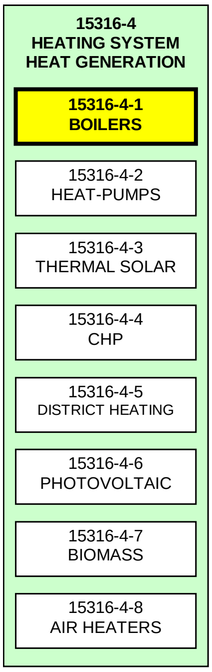
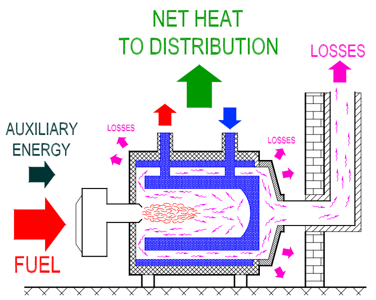


Figure 2: Part 4 of EN 15316 covers generation sub-systems. Separate sub-parts cover the various generation devices



Fuel input	$E_{H,gen,in}$
= net heat to distribution	$Q_{H,gen,out}$
– recovered auxiliary energy	$Q_{H,gen,aux,rvd}$
+ losses	$Q_{H,gen,ls}$

$$E_{H,gen,in} = Q_{H,gen,out} - Q_{H,gen,aux,rvd} + Q_{H,gen,ls}$$

Figure 3: Generation subsystem basic energy balance.

Domestic hot water generation sub-systems are treated in the standard EN 15316-3-3. However, this standard may be used to assess the heat generation for hot water production when an indirectly heated storage system is using the heating boilers as heat source. Required heat output for domestic hot water distribution (or storage) is taken into account as input data in this case.

In the case of multiple generators, the total required heat output to the connected distribution subsystem(s) shall be distributed amongst the available generation subsystems (individual heat output required from each generator), taking into account any priority or limit. With this input data, each generation subsystem shall be calculated according to the relevant part of EN 15316-4.

2 > Principle of the methods

The three methods calculate fuel and auxiliary energy consumption of one or more boilers to fulfill the heat demand of the attached distribution subsystem(s). Boiler performance may also be given as an (annual) efficiency.

The methods take into account boiler heat losses and/or recovery due to the following physical factors (see **figure 3**):

- flue gas losses (burner on);
- draught losses (burner stand-by);
- envelope losses (burner on and stand-by);
- auxiliary energy use (standby/electronics, gas valve, pump, fan);
- auxiliary energy recovery.

The common input data is the heat required by the attached distribution sub-system(s) $Q_{H,dis,in}$. Optionally, the additional load for domestic hot water distribution subsystem $Q_{W,dis,in}$ may be taken into account when using a single generator for both services.

Other input data is required to characterize:

- type and characteristics of the heat generator(s) (atmospheric, condensing, etc.);
- location of the heat generator(s) (heated room, unheated room, ..);
- operating conditions (time schedule, water temperature, etc.);
- control strategy (on/off, multistage, modulating, cascading, etc.).

The basic outputs are:

- fuel consumption $E_{H,gen,in}$;
- auxiliary energy consumption $W_{H,gen,aux}$;

that are used as an input in EN 15603 to calculate primary energy required by the heating system.

Other optional output information that may be extracted relates to:

- generation total heat loss (flue gas, draught and envelope losses);
- recoverable generation heat losses (explicit or already taken into account as a reduction of losses = recovered losses)
- seasonal generation efficiency.

Three performance calculation methods are described:

- boiler typology method;
- case specific method;
- boiler cycling method.

These three methods are worked out below.

Table P.1: Gross boiler seasonal efficiency for single boiler for heating
Source: NL

Boiler type (efficiencies at net values)	Gross seasonal boiler efficiency
Local gas or oil heater (incl. pilot flame)	65 %
Gas fired air heater (excl. pilot flame)	
– no test data	75 %
– full load net efficiency >= 88,5 %	80 %
– Gaskeur HR 100 label (part load net efficiency >= 101 %)	90 %
– Gaskeur HR 104 label (part load net efficiency >= 105 %)	92,5 %
– Gaskeur HR 107 label (part load net efficiency >= 108 %)	95 %
Oil fired boiler for a single dwelling, within the heated space or Oil fired boiler for a non residential building with a “user surface” <= 500 m^2, within the heated space. Efficiency excl. pilot flame.	75 %
Oil fired boiler for a single dwelling outside the heated space or Oil fired boiler boiler in a collective heating installation for more dwellings or Oil fired boiler for a non residential building with a “user surface” > 500 m^2 or with the boiler outside the heated space. All efficiencies excl. pilot flame.	70 %

Figure 4: Sample efficiency table for boiler typology method (source: NL).

The following types of input data may be used as available:

- data declared by the boiler manufacturer;
- on site measurements;
- tabulated default data.

3 > Boiler typology method.

This method is defined in clause 5.2 of EN 15316-4-1 and is based on pre-calculated annual efficiencies, depending on a limited set of data which may consist of a table and/or simple correction formulas. An example of this method, developed for the UK, is given in Appendix A of the standard. The Netherlands uses this type of method, but applied utilizing a different approach.

The method requires a specific national annex with tables and/or formulas, suitable for the climate and installation characteristics. This is required, because annual boiler performance depends strongly on boiler load, design temperature, control strategy, boiler room temperature, outdoor climate and boiler parameters. For buildings with equal installation design and equal boiler efficiencies, similar generation seasonal efficiency will be found.

The procedure to determine (national) precalculated values involves:

- Identify repetitive heating system typologies.
  Typical installations schemes should be identified, taking into account
  - boiler type (atmospheric, forced draught, condensing…);
  - individual/collective systems;
  - system design temperature;
  - control strategy (heating curve, room thermostat);
  - boiler room type (heated, unheated);
  - installation year (effect of regulation changes, fuel).
- Identify basic operating conditions (average monthly load profile, average temperature levels according to emitters and common design practices).
- Identify other relevant boundary conditions that may influence performance.
- Identify classes of boilers, according to part load and/or full load efficiency (this may be related to national label systems).
- Perform the calculations with a detailed method and get the correlation factors for the tables (efficiencies, loss factors, etc.) in the various identified conditions.
- Verify compatibility in the case of multiple corrections.

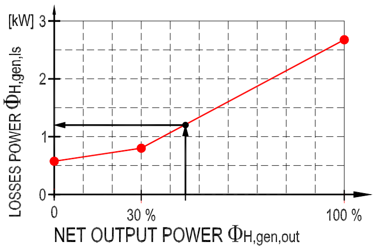


Figure 5: CASE SPECIFIC METHOD Graph showing the basic linear relationship between output load ΦH,gen,out and losses power ΦH,gen,ls. Interpolation is here made between part load and full load.

The calculation methods mentioned below can be used to obtain the table values. Also, other validated boiler models may be used.

This method is suitable for new boilers and existing boilers with a (national) label or other efficiency indication. The method may include corrections for measured efficiencies (usually based on flue gas measurement, see EN 15378).

4 > Case specific method

This method is defined in clause 5.3 of EN 15316-4-1.

The considered calculation interval of this method can be the heating season, however a shorter period (month, week, or the operating modes) is preferable.

For the calculation period the full load, part load and stand by power

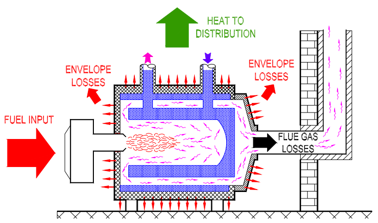


Figure 6: Boiler cycling method
Heat flows and losses with burner ON

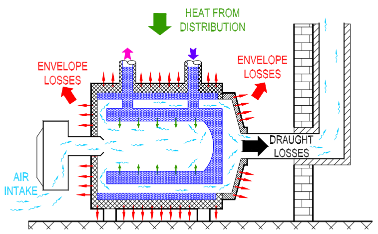


Figure 7: Boiler cycling method
Heat flows and losses with burner OFF

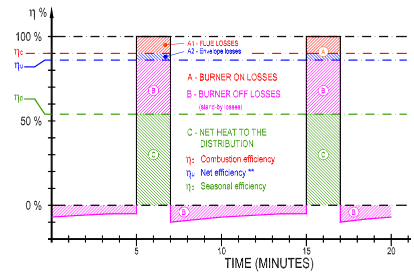


Figure 8: Graph showing the combination of losses during boiler on- and off-time and corresponding efficiency definitions.
A + B + C is the fuel used but the net useful heat to distribution is only C
A are burner ON losses
B are burner OFF losses

losses are calculated from net efficiency data, corrected for real operating conditions. Real losses are found by interpolation of losses power between the two nearest output load situations (see **figure 5**). A similar interpolation is performed to calculate auxiliary energy required by the boiler.

Fuel input is calculated by adding losses to required net output, taking into account recovered auxiliary energy.

Boiler type (atmospheric, forced draught, condensing, etc.) and control (single stage, modulating, etc.) are taken into account in the boiler efficiency input data. Actual operating conditions are taken into account through correction of efficiency data.

Parameters required to characterize the boiler are:

- generator output at full load (reference boiler power);
- generator efficiency at full load;
- generator average water temperature at test conditions for full load;
- generator output at intermediate load;
- generator efficiency at intermediate load;
- generator average water temperature at test conditions for intermediate load;
- stand-by heat loss at test temperature difference;
- difference between mean boiler temperature and test room temperature in test conditions;
- power consumption of auxiliary devices at full load;
- power consumption of auxiliary devices at intermediate load;
- stand-by power consumption of auxiliary devices;
- minimum operating boiler temperature.

Full load and part load test data are generally available for new or recent boilers as they are required by the Boiler Efficiency Directive (92/42/EEC). For existing old boilers, these data are generally not available

Standby-losses and auxiliary power consumption data are generally not available.

Default data shall be given in a national annex to complete data for new boilers, and to use this method for existing boilers, as these factors are not easily measured directly.

Additional boiler input parameters are:

- correction factor of full-load efficiency;
- correction factor of intermediate load efficiency.

No procedure to determine these data is given. They should be given in a national annex. Annex B of the standard gives default values for these factors.

Actual operating conditions input data are:

- net heat output to the heat distribution sub-system(s);
- average water temperature in the boiler;
- return water temperature to the boiler (for condensing boilers);
- boiler room temperature;
- temperature reduction factor depending on the location of the generator.

These data should come from calculations according to other parts of EN 15316 or from default values.

Annex B to the standard contains a complete set of default parameters for this method that can be used as a reference and template to develop a national annex.

5 > Boiler cycling method

According to the combustion technique there are:

- *atmospheric burners*
- *forced draught burners*
- *premixed burners*

According to the heat output control there are

- *single stage boilers*
- *multi-stage boilers*
- *modulating boilers*

According to the capability to recover latent heat from the flue gases

- Non-condensing boilers
- Condensing boilers

Generation capacity may be split over different generators; splitting; splitting ranges from a single boiler to a cascade connection of up to 8 boilers (modular units)

Other factors may influence significantly generation performance:

- *indoor/outdoor boiler installation*
- *sizing of the boiler in comparison with actual building needs (load factor effect)*
- *hydraulic connection with the heating system*

Fitting this big variety of boilers and influences into a single method is challenging.

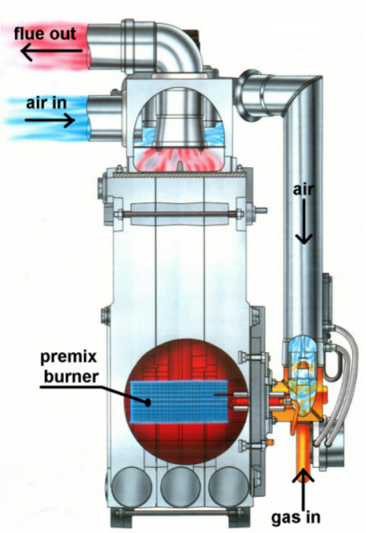


Figure 9: Boiler typology- e.g. Premix type burner

This method is defined in clause 5.4 of EN 15316-4-1. This method performs an analysis of boiler losses.

The calculation interval for this method is usually one month, but can also be a shorter period.

For single stage burners, the calculation interval is divided into two situations, with specific loss calculation for both situations:

- **Burner ON** time (see **figure 6**)
  flue gas losses and envelope losses are considered here;
- **Burner OFF** time (stand-by) (see **figure 7**)
  draught losses and envelope losses are considered here.

Figure 8 is showing the combination of the two situations.

For each calculation interval the burner-on time is calculated depending on the system heat demand. For both on and off-time, losses are calculated using boiler characterization data, correction formulas and tabulated parameters to take into account actual operating conditions (i.e. water temperature).

The required amount of fuel is obtained according to combustion power and calculated on-time.

Boiler type (atmospheric, forced draught, condensing, etc. see **figure 9**) is taken into account through specific loss factors.

Multistage and modulating generators (effect of burner control) are taken into account by addition of a third reference state: burner ON at minimum continuous power. The performance of these boilers is calculated assuming that the following operating conditions are possible:

- if the power required by the distribution system is less than the minimum ON power, the boiler will cycle just as a single stage boiler;
- if the power required by the distribution system is higher than the minimum ON power, the boiler will stay ON continuously and its loss factors are calculated by interpolation between minimum load and maximum load values.

The same method is used, with some adjustments, to deal with modular boilers (i.e. a set of interconnected small boilers).

Condensation latent heat recovery is calculated according to flue gas composition and temperature and taken into account as a "bonus" (reduction) of flue gas losses.

Flue gas temperature is calculated as the sum of:

- water return temperature, which depends on the operating conditions of emitters and distribution system (heating system effect);
- temperature difference between flue gas temperature and water return temperature (boiler effect).

Actual operating conditions are taken into account through correction of loss factors according to water temperature and load and calculation of flue gas temperature (for condensing boilers).

Basic boiler characterization input parameters (single stage) are:

- maximum combustion power of the generator (test conditions);
- heat loss factors at test conditions for flue gas losses (burner on), draught losses (burner stand-by) and envelope losses (burner on and stand-by);
- average boiler water temperature at test conditions for burner on;

Boilers typologies, age, maintenance status are extremely various.
Some pictures show what can be found out there when dealing with existing boilers.

Old atmospheric boiler in a boiler room

A couple of recent boilers installed outdoors

Force draught boiler within a boiler room

Figure 10: Examples of existing boilers

- average boiler temperature at test conditions for burner off;
- temperature of test room;
- electrical power consumption of auxiliary appliances (before the generator, typically burner fan) and related recovery factor;
- electrical power consumption of auxiliary appliances (after the generator, typically primary pump) and related recovery factor.

For condensing boilers, the following additional input data are required:

- temperature difference between flue gas temperature and boiler return water temperature;
- flue gas oxygen content.

For multi-stage and modulating burners, the following additional data are required:

- minimum combustion power with burner on;
- heat loss factors for flue gas losses (burner on) at minimum combustion power;
- auxiliary energy power at minimum combustion power.

For multi-stage and modulating condensing boilers, the following additional data are required:

- temperature difference between boiler return water temperature and flue gas temperature at minimum combustion power;
- flue gas oxygen contents at minimum combustion power.

Full load and part load flue gas losses with burner on are generally available for new boilers. Standby-losses and power consumption data are not typically available, nor are they easily measured.

Additional data for condensing boilers are not always available but are easily measured.

For existing boilers (see **figure 10**) data may not be available. Only flue gas losses with burner on and additional data for condensing boilers are easy to obtain by direct measurement.

Missing data shall be estimated using tables with default values. Annex C to 15316-4-1 gives an example of such tables.

Additional boiler input parameters:

- exponents n, m and p for the correction of heat loss factors.

No procedure to determine these data is given. They should be given in a national annex. Annex C to 15316-4-1 gives an example of such tables.

Actual operating conditions input data:

- net heat output to the heat distribution sub-system(s);
- average water temperature in the boiler;
- return water temperature to the boiler (for condensing boilers);
- boiler room temperature;
- reduction factor taking into account recovery of heat losses through the generator envelope, depending on location of the generator.

These data should come from calculations according to other parts of EN 15316 or from default values.

Annex C to the standard contains a complete set of default parameters for this method that can be used as a reference and template to develop a national annex.

Boiler cycling method concepts may be used as a basis to generate simplified methods for in-situ evaluation of seasonal energy performance of boilers. An example can be found in EN 15378 (boiler and heating system inspection).

6 > FAQ

Why 3 methods?

No single method provides a correct solution for all cases. A simplistic method may not be able to show the effect of improvements, whilst a detailed method may be unecessarily time consuming for common situations.

The boiler typology method has proven to be a reliable and easily applied method, suitable for use by people with minimal modeling skills in common situations.

The other two methods may be used to determine the values for the typology method. They also may be used for situations out of scope of the typology method.

Additional (national) annexes for specific parameters are required, to avoid confusion regarding the use of the method and discussions on the reliability of the results.

What was the aim in developing the 3 methods?

The boiler typology method aims to extreme simplicity.

The case specific method is meant to use as far as possible boiler directive data.

The boiler cycling method is meant to deal with existing boilers/buildings, to keep a connection with directly measurable parameters and to calculate operating performances of condensing boilers.

Are national annexes always required?

The boiler typology method requires that a national annex be developed, as tables contain efficiency values that are calculated to reflect common situations which are specific to each country. Default values include the effect of varying legislation (→ time references in tables), product development, design practice, climatic effect, system typologies etc., all of which are potentially variable between countries. Annex A is an example of the result of this analysis for the UK.

Case specific and boiler cycling methods come with annexes (annex B and C) where default values are given to cover a much broader set of cases, and adjustments may be required to develop a national annex using them as a template.

Where do the methods come from?

The boiler typology method is a general table-approach method.

The case specific method is based on the French TH-2000 rules.

The boiler cycling method is based on the Italian standard UNI 10348.

What if I have more generation subsystems?

The total heat input to all connected distribution subsystems shall be calculated first.

Then the share amongst the available generation subsystems (individual heat output required from each generation subsystem) shall be determined, taking into account any priority or limit.

Each generation subsystem shall be calculated according to the relevant part of EN 15316-4.

What is the potential impact of boiler generation subsystem?

Boiler seasonal efficiency can roughly range from 70% to 105% (based on lower calorific value), with reference to oversized on-off atmospheric boilers and correctly operating modulating condensing boilers, respectively.

A low load factor has a larger negative impact on traditional (non condensing) boilers.

Condensing boiler performance depends on actual operating conditions (load and water temperatures), covering a range of approximately 10%.

7 > References

1. EN 15316-4-1Combustion systems
2. EN15316-2-3 Heating distribution subsystem
3. EN15316-3-3 Domestic hot water generation subsystem
4. EN 15603 Overall energy use
5. EN 15378 Inspection of boilers and heating systems

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