Facts and figures about domestic gas boilers

A compilation of results covering 25 years of testing at DGC's laboratory

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Danish Gas Technology Centre
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Introduction

The purpose of this report is to present facts and figures about domestic gas boilers' performance in laboratory and in real installations.

A large number of gas boilers on the Danish market have been tested for energy performances: efficiency, electricity consumption, emissions (CO, NOₓ) for heating. Also hot water efficiency is measured.

These tests were primarily conducted on DGC's boiler test rig, which is accredited by DANAK for the purpose.

This document is based on the above test results and general knowledge from other projects and recognized institutes working with boilers.

The document includes:

1. Explanations and definitions for efficiency, annual efficiency, hot water efficiency, emissions, electricity consumption.
2. Explanation about how the performances of gas boilers can vary with heat demand, hot water demand, radiator installations etc.
3. Statistical data on gas boilers tested at DGC: Tables with nominal efficiency, hot water efficiency, annual efficiency, NOₓ and CO emissions for about 200 boilers. Average per type and age etc.

This report has been written by Jean Schweitzer (DGC) for the TCG (group of technical managers of the Danish gas distribution companies). The QA was made by Leo van Gruijthuijsen (DGC).

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1 The scope of this document is domestic boilers below 70 kW (limit used in standards), but the most common domestic boilers have a nominal input below 30 kW or so.
Main results

Boiler efficiency

The average annual efficiency of the most recent boilers (2010-2015) for few standard heat demands and hot water needs is given here below for few installation conditions.

\[ HW = \text{Hot water} \quad TT = \text{traditional temperature} \quad LT = \text{Low temperature} \quad MX = \text{Mix (50\% TT \\ & 50 \% LT)} \]

<table>
<thead>
<tr>
<th>Heat demand kWh/year</th>
<th>without HW</th>
<th>with 1000 kWh HW</th>
<th>with 2000 kWh HW</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LT</td>
<td>TT</td>
<td>MX</td>
</tr>
<tr>
<td>18000</td>
<td>105,1</td>
<td>101,7</td>
<td>103,4</td>
</tr>
<tr>
<td>20000</td>
<td>105,7</td>
<td>102,5</td>
<td>104,1</td>
</tr>
<tr>
<td>22000</td>
<td>106,3</td>
<td>103,3</td>
<td>104,8</td>
</tr>
</tbody>
</table>

The average for a 20,000 kWh heat demand + 2,000 kWh hot-water demand is about 101\% (net) for a standard installation according to the building regulations in force in Denmark since 2005.

The above figure includes the hot water tank losses. For a more detailed analysis and other assumptions see section 3.11.

As shown in the table, the efficiency is depending on:

- The actual heat demand and hot-water demand
- The type of distribution system. The “low-temperature” system is according to the building regulations 2005. Pure floor heating systems have even lower temperature and will have higher efficiencies.

The efficiency can be slightly higher or lower (±3\%) depending on the model of the boiler chosen.

The annual efficiency of gas boilers has increased by about 20\% when comparing the most recent condensing boilers with the traditional boilers from the 1990s.

The figures above are derived from laboratory test and cross-checked with some field data.
Other parameters

As for efficiency, the other performances of boilers have improved quite a lot over the last 3 decades.

Electricity consumption is today between 150 and 220 kWh (depending on the pump control), whereas it was about 550 to 650 in the 1990s.

NO\textsubscript{x} emissions have also decreased quite a lot with the use of new modulating burner technology.

The above improvements are very much linked to technology improvement combined with consumer information and the energy labelling that was introduced in Denmark long before the EU boiler labelling.

Guide for the reader

The report is targeting energy experts who need to have specific data and information on gas boilers as well as non-technical readers who need information on topics such as gas boiler efficiency etc.

Section 1 gives explanations about gas boilers and heating systems. Readers familiar with this may skip this section and go on to Section 2.

Section 2 deals with nominal performances of boilers measured in laboratory. In this section we first present in detail the profile of DGC's database that is used further in the report. Statistics on nominal performances (efficiency etc.) are given and discussed in detail. Furthermore, graphs and tables are presented to show the evolution of nominal performances of gas boilers.

Section 3 is about annual performances of boilers with a strong focus on efficiency.

Section 4 covers discussion points and frequently asked questions about annual efficiency.

Finally, Section 5 covers other relevant aspects (reliability of boilers etc.)
Main abbreviations used

**Pin**: Heat input [kW] (see also 2.2)
The heat input in the “standard” language for boilers is the quantity of energy (in the gas) per unit of time. It is expressed on the net calorific value unless otherwise specified.

**Pout**: Heat output [kW] (see also 2.2)
Similarly the heat output is the quantity of energy in the water coming out of the boiler per unit of time.

**Hi** [MJ/m^3] Net (also called “low”) calorific value of the gas

**Hs** [MJ/m^3] Gross (also called “high”) calorific value of the gas

**TT** = Traditional temperature (see also 3.8)

**LT** = Low temperature (see also 3.8)

**HW** = Hot water (sanitary hot water)

**GAD** = Gas appliances directive

**UHC** = Unburned hydrocarbon

**Efficiencies in the present report are expressed on the net calorific value unless otherwise specified.**
1 Explanations about gas boilers

1.1 What is a gas boiler?

A gas boiler is an appliance burning gas to produce heat that is transferred to water used for space heating and possibly sanitary hot water. In a gas fired boiler, gas is burnt in a combustion section. Heat is transferred to water through a heat exchanger after the combustion section. Domestic gas boilers are generally equipped with a pump that circulates the heated water in the heat distribution system (radiators, convectors, floor heating) of the house or dwelling /2/.

The combustion of natural gas produces CO$_2$ and water vapour through reactions between oxygen (O$_2$) and gas carbon (C) and hydrogen (H). The latent energy content in water vapour in the flue gas represents an equivalent to the energy required to bring the volume of water from liquid to vapour form. The amount of energy corresponds to the difference between natural gas gross and net calorific value (H$_s$, Hi).

An example of conversion Hi/Hs with Danish natural gas is given in the Annex3. The ratio H$_s$/Hi is between 1.10 and 1.11 for most natural gases (category H).

A condensing boiler is a boiler designed to recover latent heat from water vapour produced during the combustion of the gas. In condensing boilers, the flue gas is cooled down to a temperature at which water vapour condenses. All or part of the energy that water vapour contains is recovered. For condensing boilers, the condensation takes place at temperatures below 60 °C (dew point temperature), depending on how much additional air (excess air) the exhaust gas contains.

The excess air is dependent on the burner type. Condensing boilers nowadays are all equipped with full premix burners. This means that the air used for the combustion is mixed with the gas before the combustion starts.

The figure below shows the dew point as a function of CO$_2$, which for most condensing premix boilers is in the range of 8-10 %, thus giving a dew point temperature in the range of 53 to 56 °C)
DGC report

Water vapour dewpoint
for natural gas

Dew point and CO₂ /9/

CO₂ at full load for boilers. To the right: condensing boilers (all equipped with full premix burners CO₂ > 8%. To the left: traditional boilers (mostly atmospheric burners). Source: DGC’s database.

For a total condensation of the water in the flue gas on the boiler heat exchanger, the increase of the amount of energy released is approximately 11%, (of the net heat input).
When efficiency is calculated relative to net calorific value, the highest theoretical efficiency of condensing boilers becomes 111%. In order to achieve this efficiency, all the water vapour in the flue gas is condensed, and flue gas temperature must be 25 °C.

For condensing boilers, condensation is almost always achieved in practice, as the water return temperature in the heating system most of the time is below the dew point temperature (see 1.1.4)

A condensing boiler includes two stages of heat collection.

1. Flue almost dry at the chimney exit
2. Sealed and corrosion resistant chimney
3. Insulation
4. “Primary” heat exchanger
5. Return water
6. Flow water
7. “Secondary” heat exchanger area
8. Fan
9. Trap

Example of a sectional scheme of a condensing boiler /21/.

In the first stage, the primary heat exchanger collects the heat directly from the hot gasses, as it occurs in a traditional boiler. In the second stage, the secondary heat exchanger collects the latent heat, which is gained by condensing the water vapour from the flue gases. Some condensing boilers integrate these two stages of heat collection in the same heat exchanger.

Note that condensing boilers need a condensate evacuation system.

“Traditional boilers” do not recover latent heat from water vapour produced during the combustion of the gas.
Apart from a single exception (B1 type boiler), traditional boilers have been banned from the EU market from 26.09.2015 (Ecodesign directive) /7/. In many countries like Denmark, The Netherlands, etc., condensing boilers have been the “standard” boilers for the last decade or more.

1.2 Control systems of boilers

In order to command the heat production, boilers need a control system that is either built in the boiler or mounted by the installer. The control system monitors and optimizes the operation of the boilers to produce the heat needed to maintain the indoor temperature of houses to the value desired by the user.

There are two main control systems principle:

- The room thermostat, controlling the boiler depending on the indoor temperature in the house.
- The outdoor temperature based control: The water temperature in the heat distribution system is inverse-proportional to the outdoor temperature.

Example of a heating curve showing the water temperature as a function of the outdoor temperature.


In addition, thermostatic radiator valves can be installed in order to control the temperature room by room in the house.
In Denmark, the most common control system is the second one (outside temperature based control).

1.3 Combustion control
With gas quality variations in Europe, some manufacturers have started to develop systems that would allow accommodating gas quality variations.

One of the most known systems is based on the measurement of flame ionization in the combustion flame. This principle is already used for safety function as flame-control (no ionization signal = no flame – the gas valve is closed).

The ionization signal can be measured and can also be used for a combustion control system: The flame temperature (ionization voltage) is directly related to the air factor, the ionization signal is an indication of the quality of combustion.

Several manufacturers use this type of active combustion control in their wall hung gas condensing boilers (Scot system). Information on other control systems technologies (CO, O₂, etc.) can be found e.g. in /20/.

1.4 Other features of gas boilers
Gas boilers can be wall hung or floor standing. This feature does not impact boiler performances.

Boilers can be designed to produce either heat only or both heat and sanitary hot water (in the last case they are named “combi”). Hot water can be produced directly by the boiler (instantaneous), or the boiler can be used to heat up a water tank. In the first case, the boiler may need to have a nominal output of about 32 kW in order to be able to cover most of the users need (value applicable for Denmark in order to respect the Code of Practice for domestic water supply installations ("the water norm") /23/.

The main advantage of an instantaneous boiler is that it will save space (no water tank), and that the cost may also be slightly lower. On the other hand, there is an additional (but short) waiting time, as the boiler only starts a few
seconds (pre-ventilation of the combustion room) after the user has opened the water tap.

Most modern boilers are modulating: This means that they can produce heat in a given range (from $P_{\text{min}}$ to $P_{\text{max}}$) without burner stop. The main advantage of this technology is to avoid too frequent start-stop so it improves comfort and reliability.

$P_{\text{min}}$ and $P_{\text{max}}$ are often called nominal values, as they are a characteristic of the boiler under “nominal”, theoretical conditions (tested in lab) as opposed to real conditions where the power varies dynamically.

1.5 Installation aspects

Boilers in Denmark are installed and maintained by professional, qualified installers. They are educated to install appliances according to regulations, manufacturer’s instructions and good practices in order to achieve the best performances of the appliances. This is important as parameters like annual efficiency are depending on the installation (see section 3).
2 Nominal performances of gas boilers measured in laboratory

What is meant by nominal?

- Definition of efficiency heat input, heat output, space heating efficiency
- Boiler losses
- Hot water efficiency
- Boiler emissions
- Boiler electrical consumption

2.1 Introduction

2.1.1 What are nominal performances of gas boilers, full load and part load?

The terminology “nominal” originates from the testing standard describing how to test boilers for CE or other approval. The term “nominal” applies to test conditions for measurements in the laboratory. It refers mainly to water temperature conditions. For example 60/80 °C water temperature set is one of the typical set for nominal tests.

So nominal performances are obtained when measuring appliances in the laboratory and cannot be used directly to assess performances of installed appliances. Therefore, the concept of annual (also called seasonal) performances was developed. Nominal performances data are used to calculate annual performances (see section 3).

At the time of "on-off" boilers, the terms of full load and part load were used to describe the situation where the boiler was continuously running at full load (Pmax) and working in start-stop mode to achieve lower loads (part load).

The introduction of modulation technology has to some extent complicated the definition as modulating boilers can work at "part load" without start-stop. But the definition generally used is to use "full load" for Pmax and Pmin (the extremes of the modulation range) and part load for any other load, regardless if the boiler is starting-stopping or not.
A standard test point for boilers is the "30 % part-load test" and for modulating boilers this point may or may not be the modulation range.

2.1.2 Origin of data in this section

All data in this section are data measured by DGC's accredited laboratory during the period 1991-2015 (apart from a few boilers for which third-party data from test laboratories have been given to DGC by the manufacturers – mainly in the case of boiler families with the same construction, but different sizes, and for which we have not carried out testing ourselves). The original purpose of the test is information to customers and professionals (see below).

During this period of time, DGC participated in numerous inter-comparisons with other leading EU laboratories in order to ensure that measured results are comparable within the EU. About 250 boilers were tested during this period. The tests were carried out in agreement with the manufacturers and the Danish gas industry. The objective of those tests was to get a fair assessment of appliances on the market in order to help the consumer to choose appliances.

The results were disseminated to users by the following means:

- Articles in consumer magazine (Råd & Resultater)
- Boiler list on DGC's website
- Boiler labelling (before the introduction of EU labelling in 2015)
- GASPRO² (test data are used as input parameters for GASPRO)
- Gas distribution companies' show rooms
- Etc.

As the testing started in 1991, the database covers a large variety of boilers, from atmospheric boilers, the first condensing boilers to up-to-date condensing technology of 2015 (date of this report).

The earlier data are still used today, as these boilers are the boilers that are today being replaced by new technologies. The knowledge of older boilers is therefore very useful to assess the energy saving of boiler replacement.

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² GASPRO is a tool developed by the Danish gas industry aiming at calculating the annual performances of tested boilers (see also next section) for a given installation, taking into account the real installation (radiator size, etc.)
2.1.3 Appliances used for the statistics in the present report

The choice of appliances to be tested is entirely the manufacturer's decision. In general, the boilers tested are the most popular products of the manufacturers and are appliances that represent a significant part of the population of appliances installed in Denmark today. A study /18/ has shown that the available data for boilers tested covers about 35% of the present population of installed boilers in Denmark. The other 65% consist of boilers that were introduced on the Danish market before DGC started the testing in 1991, or introduced on the market without DGC testing.

Most boilers sold on the Danish market are boilers delivered with a water tank for the production of sanitary hot water. But instantaneous appliances are also on the market, and some were also included in the testing programme.

In the first case, the water tank is also chosen by the manufacturer. It is chosen to reflect the typical size sold with the considered boiler. In practice, most of the storage tanks are in the range from 60 to 120 l.

Appliance “selected”

Despite the fact that we have tests results for more than 250 boilers, “only” 190 have been used in the statistics for the main reason that not all test data could be directly compared with each other.

One of the reasons is that the testing procedure was changed at the beginning of the 2000s, and a number of data needed to be reprocessed in order to be able to compare results over the last 25 years. In the frame of this project, we were not able to include all data/boilers.

2.1.4 Overall Profile of the appliances in the database

The following describes the profile of the boilers of the database, which is used to make the further statistics and calculation in this report.

Heat input range

The following graph shows the heat input of the boilers (in a chronological, but not linear, way). Pmin and Pmax are given (for non-modulating boilers the graph does not show Pmin).
As seen on the figure all boilers tested from about 1998 are modulating. This is not reflecting a deliberate choice not to test non-modulating units, but rather the situation of the market. Most of the boilers tested are in the range 15 to 30 kW (for Pmax).

In the early 1990s, the modulation range was rather limited (ratio of Pmax/Pmin about 2). But this ratio rapidly increased from about 1995 to reach up to almost 10 for some boilers after 2010.
Condensing and traditional
Most of the boilers in the early 1990s were traditional, but the market changed rapidly to condensing only. The database comprises 83% of condensing boilers.

Hot water production
Most of the market in Denmark is for boilers with water tanks, and this is also reflected by the testing where instantaneous appliances are in the minority.
The volume of storage tanks of appliances tested is in the range 10-175 l! Small capacity tanks (e.g. 10 l) are sometimes built in boilers as buffer. The boiler can basically be considered as an instantaneous boiler with a small buffer tank. On the other extreme tanks up to 175 l have been tested.

The choice of the tank volume is a compromise. If the tank has a large capacity, the boiler water production power does not need to be very high; but with low or no storage capacity, the hot water production power needs to be high. Large storage also means larger losses, so the choice of combination boiler/tank is a compromise depending on the manufacturer target. The average water tank for the sample tested is about 75 l.

### 2.2 Some explanation of parameters measured in laboratory

#### 2.2.1 Definition of efficiency heat input, heat output, space heating efficiency

The **heat input** is defined as the input power given by the gas. It can be expressed on the **lower calorific value** of the gas (Hi) or the **upper calorific value** of the gas (Hs). For most of gases the ratio Hs/Hi is between 1.10 and 1.11 (see also annex3).

The **heat output** is defined as the useful power delivered to the water when burning gas.
The **boiler efficiency** is the ratio of heat output/heat input

Values of efficiency must always be considered with the conditions, in which they are measured and expressed:

- Hi or Hs
- Pmax, Pmin or any other load
- Water temperature

For **emissions**, the gas used is also an important parameter as e.g. NOx is very depending on gas composition.

Without the details about test conditions it is not possible to compare efficiencies. Furthermore, there are several methods for calculating **annual efficiencies** (see section 3) aiming at calculating efficiency over an entire heating season. This annual efficiency may or may not include **sanitary hot water production**.

DGC's test programme usually covers several test conditions in order to have a clear picture of how load and temperature are influencing the boiler nominal efficiencies, and how gas composition influences the NOx emissions.

<table>
<thead>
<tr>
<th>Test</th>
<th>Load</th>
<th>Temperature (in/out) in °C</th>
<th>Gas</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Full load Pmax</td>
<td>60/80</td>
<td>NG from the net</td>
</tr>
<tr>
<td>2</td>
<td>Full load Pmax</td>
<td>40/60</td>
<td>NG from the net</td>
</tr>
<tr>
<td>3</td>
<td>Full load Pmax</td>
<td>30/50</td>
<td>NG from the net</td>
</tr>
<tr>
<td>4</td>
<td>Full load Pmin</td>
<td>60/80</td>
<td>NG from the net</td>
</tr>
<tr>
<td>5</td>
<td>Full load Pmin</td>
<td>40/60</td>
<td>NG from the net</td>
</tr>
<tr>
<td>6</td>
<td>Part load 30%</td>
<td>30/36</td>
<td>NG from the net</td>
</tr>
<tr>
<td>7</td>
<td>Part load 30%</td>
<td>47/53</td>
<td>NG from the net</td>
</tr>
<tr>
<td>8</td>
<td>Full load Pmax</td>
<td>60/80</td>
<td>Pure CH₄</td>
</tr>
</tbody>
</table>

The extensive test programme above has allowed us to create a unique knowledge on how load and water temperature are influencing the boiler efficiencies. This has been further used to validate the calculation programme BOILSIM, used for the annual efficiency (see section 3).
For all the tests above, efficiency, electricity consumption and emissions are measured.

In earlier stages (1995), DGC's test programme also included more part-load tests (1 kW, 2 kW, 4 kW, etc.), but comparisons with the model developed (BOILSIM, see /10,14,15/) showed that we were able to calculate those accurately with the test programme described above.

In addition to efficiency and emission tests, standby losses are also measured, as well as hot water production.

2.2.2 Boiler losses

The differences between heat input and heat output are due to the boiler losses.

Boiler heat losses are composed of two main elements:

- **Flue gas losses** (the combustion products are hot and therefore carry part of the heat energy out of the boiler into the outside air)
- **Case losses** that are transferred into the boiler room.

Note that if the boiler room is part of the heated space, the heat transferred by the boiler case is not a loss anymore, as it contributes to the heating of the room.
The annual efficiency method used in this document is conservative on this point as the case loss is considered as loss, and therefore we use the hypothesis that the boiler is installed in an unheated room.

In practice, there can also be another loss: The **fuel loss (unburned hydrocarbons)**. According to rough evaluations some authors /9/ suggest a value of 1.4% fuel loss for the population of installed appliances, but according to other sources /22/ unburned hydrocarbons, on modern gas burners, are very low and occur at the ignition phase of some burners (mainly depending on the position of the ignition system and gas entry). Moreover, the energy balances made on the more than 200 part-load boiler tests (start-stop frequency = 6 per hour) at DGC have not shown any evidence of losses of such magnitude when making the heat balance.

**Pre- and post-purge loss** is occurring during the purge of the combustion room of a boiler. For safety reasons, the combustion room of some boilers needs to be purged before each burning cycle. The loss depends on the fan running time. As above, it is taken into account in our method of annual efficiency as described in section 3.

**Draught losses** are losses through the chimney during off-time of the burner. They may or may not be included in the standby loss depending on the measurement method used. Again, as above, it is taken into account in our method of annual efficiency as described in section 3.

Finally, if the pump of the boiler is within the system boundaries, it is important to take this element into account as a part of the electricity used by the pump is transferred as heat to the water. Very detailed investigations have been carried out and have clarified how much energy is transferred to the water in that way /19/.

The nominal efficiency of boilers is measured in a way that the pump built into the boilers has no influence on the efficiency. This is achieved either by not putting the boiler pump in operation or by correcting the efficiency measured with the pump of the boiler in operation (with /19/).

**Standby losses** are losses occurring to keep the boiler water at a certain level of temperature above ambient temperature. Standby losses are
included in the loss described above (in cases of losses and draught losses). The "concept" of standby losses was developed at a time where most boilers were maintained at a certain temperature level with a bypass independent of the heat demand. The power used by the burner to maintain the boiler in temperature was called standby loss and was an important parameter of the boiler.

Methods to measure standby loss in laboratory were developed. The straightforward way to measure standby loss was to simulate the reality and to measure the consumption of the burner when the boiler was set in a closed loop (DIN method). But this may be inaccurate and some have developed a method where the boiler is maintained in temperature by electrical elements, which is the method used in CEN standards today.

Nowadays, boilers are not maintained in temperature (apart from very few rare exceptions), but standby losses are part of testing programmes and can be used to quantify case losses of boilers.

**Typical figures of boiler loss for new condensing boilers**

**Standby losses and case losses** are small (less than 2% of the gas used as a maximum for nominal conditions (see further 2.3.1.e)), and are staying in the building envelope and also contributing to heating if installed in a heated volume of the building.

The other loss is the **flue gas loss**. For a new gas boiler, most of the losses are **flue gas losses** that are evacuated out of the building envelope through the chimney. The flue gas loss depends on the flue gas temperature and the air excess in the combustion products. Several simplified methods are used for the determination of flue gas losses and are acceptable for the sake of getting a typical figure /5/.

For instance, GASTEC (NL) uses the following simple formula /5/ for G20 gas (pure methane):

Flue gas loss (on Hi) = (0.3756/CO₂ + 0.0088)*dT [% of heat input]

With:
- CO₂ = CO₂ % in the flue gas
- dT = Tflue - Tamb
Flue gas loss (in %) for the combustion of pure methane as a function of the CO₂ value and the temperature difference (flue gas – ambient) [% of heat input]

In the following we have used nominal conditions 60/80 (in the higher end of flue gas losses compared to real installations). See section 3.8 for examples of real operating conditions. So values of flue gas losses should be considered as maximum values.

The table above is compared to real measured values:

<table>
<thead>
<tr>
<th>CO₂ (%)</th>
<th>10</th>
<th>30</th>
<th>50</th>
<th>70</th>
<th>90</th>
<th>110</th>
<th>130</th>
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<tbody>
<tr>
<td>3</td>
<td>1,3</td>
<td>4,0</td>
<td>6,7</td>
<td>9,4</td>
<td>12,1</td>
<td>14,7</td>
<td>17,4</td>
</tr>
<tr>
<td>4</td>
<td>1,0</td>
<td>3,1</td>
<td>5,1</td>
<td>7,2</td>
<td>9,2</td>
<td>11,3</td>
<td>13,4</td>
</tr>
<tr>
<td>5</td>
<td>0,8</td>
<td>2,5</td>
<td>4,2</td>
<td>5,9</td>
<td>7,6</td>
<td>9,2</td>
<td>10,9</td>
</tr>
<tr>
<td>6</td>
<td>0,7</td>
<td>2,1</td>
<td>3,6</td>
<td>5,0</td>
<td>6,4</td>
<td>7,9</td>
<td>9,3</td>
</tr>
<tr>
<td>7</td>
<td>0,6</td>
<td>1,9</td>
<td>3,1</td>
<td>4,4</td>
<td>5,6</td>
<td>6,9</td>
<td>8,1</td>
</tr>
<tr>
<td>8</td>
<td>0,6</td>
<td>1,7</td>
<td>2,8</td>
<td>3,9</td>
<td>5,0</td>
<td>6,1</td>
<td>7,2</td>
</tr>
<tr>
<td>9</td>
<td>0,5</td>
<td>1,5</td>
<td>2,5</td>
<td>3,5</td>
<td>4,5</td>
<td>5,6</td>
<td>6,6</td>
</tr>
<tr>
<td>10</td>
<td>0,5</td>
<td>1,4</td>
<td>2,3</td>
<td>3,2</td>
<td>4,2</td>
<td>5,1</td>
<td>6,0</td>
</tr>
</tbody>
</table>

Nominal CO₂/Flue gas temperature difference with ambient for test conditions 60/80 °C.

When looking at DGC's database for boilers tested (figure above) we can see that condensing premix boilers are all having CO₂ in the range 8-10 % and dT from 30 to 60 K for most of them.
Nominal flue gas loss for condensing boilers under nominal test conditions 60/80°C

Note that the above values are given for water temperature conditions of 60 °C (return) and 80 °C (forward) and can be considered as maximum figures, as the water temperature in the heating system is much lower than those nominal values.

### 2.2.3 Hot water efficiency

The **hot water efficiency** is the efficiency of the boiler (and possibly associated tank) for the production of sanitary hot water. Compared to heating the main differences impacting efficiency are as follows:

- The water temperature for sanitary hot water is generally higher than for heating.
- In case the system is a boiler + a water storage tank, the losses of the latter are to be taken into account.

As a result, the hot water efficiency is generally lower compared to heating efficiency.

Note that the hot water efficiency depends very much on the hot water demand, and that the hot water efficiency increases with hot water demand.

Efficiency for hot water is measured in laboratory with a tapping programme supposed to reflect the daily use in a family.

For instance, the CEN standard prEN 13203 suggests tapping patterns as the one below:

<table>
<thead>
<tr>
<th>dT (K)</th>
<th>10</th>
<th>20</th>
<th>30</th>
<th>40</th>
<th>50</th>
<th>60</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO2 (%)</td>
<td>8</td>
<td>0,6</td>
<td>1,1</td>
<td>1,7</td>
<td>2,2</td>
<td>2,8</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>0,5</td>
<td>1,0</td>
<td>1,5</td>
<td>2,0</td>
<td>2,5</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>0,5</td>
<td>0,9</td>
<td>1,4</td>
<td>1,9</td>
<td>2,3</td>
</tr>
</tbody>
</table>
In Denmark, there has been a tradition for using a simple tapping from the “water norm”/23/.

Here for boiler with storage tank:

_Denmark/total of about 12.88 kWh_

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4.36</td>
<td>756</td>
</tr>
<tr>
<td>2</td>
<td>4.36</td>
<td>756</td>
</tr>
<tr>
<td>3</td>
<td>1.47</td>
<td>504</td>
</tr>
<tr>
<td>4</td>
<td>1.47</td>
<td>504</td>
</tr>
<tr>
<td>5</td>
<td>0.61</td>
<td>360</td>
</tr>
<tr>
<td>6</td>
<td>0.61</td>
<td>360</td>
</tr>
</tbody>
</table>
Below is an example of measurements in laboratory for a storage appliance (DGC VA19).

![Graph showing measurements](image)

For instantaneous boilers the tapping is different (12 tappings instead of 6, but for the same amount of energy):

<table>
<thead>
<tr>
<th>Energy tapped</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>E1 [kWh]</td>
<td>1.59</td>
</tr>
<tr>
<td>E2 [kWh]</td>
<td>1.44</td>
</tr>
<tr>
<td>E3 [kWh]</td>
<td>1.46</td>
</tr>
<tr>
<td>E4 [kWh]</td>
<td>1.46</td>
</tr>
<tr>
<td>E5 [kWh]</td>
<td>1.46</td>
</tr>
<tr>
<td>E6 [kWh]</td>
<td>1.46</td>
</tr>
<tr>
<td>E7 [kWh]</td>
<td>0.62</td>
</tr>
<tr>
<td>E8 [kWh]</td>
<td>0.61</td>
</tr>
<tr>
<td>E9 [kWh]</td>
<td>0.61</td>
</tr>
<tr>
<td>E10 [kWh]</td>
<td>0.61</td>
</tr>
<tr>
<td>E11 [kWh]</td>
<td>0.61</td>
</tr>
<tr>
<td>E12 [kWh]</td>
<td>0.61</td>
</tr>
</tbody>
</table>

And the following graph shows an example of measurements in the laboratory for an instantaneous appliance (DGC VA24):
If making assumption on another hot water demand, it should be noted that the **hot water efficiency increases with the hot water demand.**

DGC has elaborated a model /5/ allowing under certain circumstances the calculation of efficiency or any tapping pattern knowing the results obtained with the Danish test method.

The main parameters that influence the tapping efficiency are:
- The actual temperature in the storage tank.
- The amount of energy tapped.
- The actual pattern of the tapping programme
- The boiler efficiency and tank losses.

As mentioned, the hot water efficiency will depend very much on the hot water demand. Keeping the hot water tank hot for a very small use of hot water is obviously not very efficient, and the more energy is tapped the lower the influence of the tank losses and, thus, the higher the efficiency. The pattern for the tapping of hot water may also have an influence. Small tapping may generate additional losses and the tapping pattern will also influence the dynamic between the boiler and the tank and the frequency of boiler start-stop.
The water tank losses depend on the tank insulation and size. /5/ gives a table that can be used for rough evaluation of tank loss:

<table>
<thead>
<tr>
<th>D/mm</th>
<th>V (l)</th>
<th>50</th>
<th>60</th>
<th>70</th>
<th>80</th>
<th>90</th>
<th>100</th>
<th>110</th>
<th>120</th>
<th>130</th>
<th>140</th>
<th>150</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>29</td>
<td>35</td>
<td>41</td>
<td>47</td>
<td>53</td>
<td>59</td>
<td>65</td>
<td>70</td>
<td>76</td>
<td>82</td>
<td>88</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>28</td>
<td>33</td>
<td>39</td>
<td>44</td>
<td>50</td>
<td>55</td>
<td>61</td>
<td>66</td>
<td>72</td>
<td>77</td>
<td>83</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>26</td>
<td>31</td>
<td>36</td>
<td>42</td>
<td>47</td>
<td>52</td>
<td>57</td>
<td>62</td>
<td>68</td>
<td>73</td>
<td>78</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>24</td>
<td>29</td>
<td>34</td>
<td>38</td>
<td>44</td>
<td>49</td>
<td>54</td>
<td>58</td>
<td>63</td>
<td>68</td>
<td>73</td>
<td></td>
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<tr>
<td>22</td>
<td>23</td>
<td>27</td>
<td>32</td>
<td>36</td>
<td>41</td>
<td>45</td>
<td>50</td>
<td>54</td>
<td>59</td>
<td>63</td>
<td>68</td>
<td></td>
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<tr>
<td>27</td>
<td>21</td>
<td>25</td>
<td>28</td>
<td>34</td>
<td>38</td>
<td>42</td>
<td>46</td>
<td>50</td>
<td>55</td>
<td>59</td>
<td>63</td>
<td></td>
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<tr>
<td>32</td>
<td>19</td>
<td>23</td>
<td>27</td>
<td>31</td>
<td>35</td>
<td>39</td>
<td>43</td>
<td>46</td>
<td>50</td>
<td>54</td>
<td>58</td>
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<tr>
<td>37</td>
<td>18</td>
<td>21</td>
<td>25</td>
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<td>32</td>
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<td>39</td>
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<td>45</td>
<td>49</td>
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<td>42</td>
<td>16</td>
<td>18</td>
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<td>26</td>
<td>29</td>
<td>32</td>
<td>35</td>
<td>38</td>
<td>41</td>
<td>45</td>
<td>48</td>
<td></td>
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<tr>
<td>47</td>
<td>14</td>
<td>17</td>
<td>20</td>
<td>23</td>
<td>26</td>
<td>29</td>
<td>32</td>
<td>34</td>
<td>37</td>
<td>40</td>
<td>43</td>
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<td>52</td>
<td>13</td>
<td>15</td>
<td>18</td>
<td>20</td>
<td>23</td>
<td>25</td>
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<td>30</td>
<td>33</td>
<td>35</td>
<td>38</td>
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<tr>
<td>57</td>
<td>11</td>
<td>13</td>
<td>15</td>
<td>18</td>
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<td>33</td>
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<tr>
<td>62</td>
<td>9</td>
<td>11</td>
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<td>15</td>
<td>17</td>
<td>19</td>
<td>21</td>
<td>22</td>
<td>24</td>
<td>26</td>
<td>28</td>
<td></td>
</tr>
<tr>
<td>67</td>
<td>8</td>
<td>9</td>
<td>11</td>
<td>12</td>
<td>14</td>
<td>15</td>
<td>17</td>
<td>18</td>
<td>20</td>
<td>21</td>
<td>23</td>
<td></td>
</tr>
<tr>
<td>72</td>
<td>6</td>
<td>7</td>
<td>8</td>
<td>10</td>
<td>11</td>
<td>12</td>
<td>13</td>
<td>14</td>
<td>15</td>
<td>16</td>
<td>17</td>
<td>18</td>
</tr>
<tr>
<td>77</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
<td>8</td>
<td>9</td>
<td>10</td>
<td>10</td>
<td>11</td>
<td>12</td>
<td>13</td>
<td></td>
</tr>
</tbody>
</table>

The losses for a tank with 27 mm insulation will be 29 W for a 70 l tank, 42 W for a 1000 l tank and 63 W for a 150 l tank, respectively.

2.2.4 Boiler emissions

Gas boilers, as most combustion processes, are producing NO\textsubscript{x} and CO. Gas boilers, however, have lower NO\textsubscript{x} emissions compared to oil boilers, due to the nature of the fuel, very little unburned hydrocarbon and very little particle emissions.

CO and NO\textsubscript{x} measured in the flue gas are diluted and need to be calculated taking into account this dilution linked to the air excess. This is done using the O\textsubscript{2} or CO\textsubscript{2} measured in the flue gas. Values measured in the flue (in ppm) are converted to neutral combustion dry gas (dry-air free or “daf”) (in ppm) or in other units as mg/kWh.

Please note that in the present report, nominal emissions expressed in mg/kWh are referring to the gas input and not the heat output of the boiler.

The most influential factor for NO\textsubscript{x} emissions is the load, and modulating boilers have in the vast majority of cases much lower emissions in the
lowest range of modulation compared to the maximum range. The average ratio of emissions is about 3 between the two operating conditions (3 times less emissions at Pmin compared to Pmax) /18/.

CO emissions are mostly related to safety and less to the environment. The GAD is setting maximum emission limits applicable for the certification of gas appliances.

2.2.5 Boiler electrical consumption

The boiler needs to be supplied with electricity in order to run some components of the boiler, such as fans, pumps, ignition electrodes etc. In general, the largest part of the electricity consumption is due to the pump. Therefore, the control of the pump is very important and has an effect on the annual electrical consumption of the boiler. The way to control the pump also depends on the type of control chosen.

The measurements carried out lead to the detailed consumption of the main components using electricity:

- The pump
- The fan of the burner
- The standby (electronics)

Note that for most of today's boilers, the pump and the fan modulate and, therefore, the electricity consumption must be measured both at Pmin and Pmax so as to enable an accurate calculation of the consumption as a function of the load.

Furthermore, the electricity consumption by hot water production may differ from the electricity consumption for heating, and here again this is measured.

For the annual electricity consumption, we calculate the running time of all components depending on the heat demand and climate (as for annual efficiency, see section 3).
2.3 Test results: Data for nominal performances of boilers installed on the Danish market. Statistics and analysis.

2.3.0 Introduction

The following data originate from DGC's extensive testing. We have tried to include as many of the boilers as possible, but some data available were not used, for various reasons, e.g.:

- When several variations of the same appliance were tested, we generally only use one (if possible the most recently tested)
- Some models have changed name during the last 25 years creating doubts about data to be used.

In the following sections we will differentiate between traditional boilers and condensing boilers, as the performances are quite different.

2.3.1 Nominal space heating efficiency and standby losses

a) Nominal full-load efficiency at $P_{\text{max}}$ evolution

![Evolution of gas boiler efficiency](image)
The full-load efficiency of traditional boilers has improved in the 1990s, but the technology was banned from the Danish market (which explains the lack of data after 2003).

The full-load efficiency of condensing boilers shows the same trend (increasing efficiency in the 1990s) and then a stabilisation in the 2000s.

The full-load efficiency for water temperature 60/80 does not show large differences between boilers, but at low temperature (30/50), variations between condensing appliances are much larger indicating that the way appliances benefit from the heat condensate is not optimal for all appliances on the market.

This is especially important to note as regulation like the ErP is based on tests such as full-load efficiency at 60/80, which is not really relevant when looking at real operating conditions of boilers.

The figure shows that for 30/50, which would be more realistic, there is also a better differentiation of appliances.

b) Nominal full load efficiency at Pmin evolution

(See definitions in section 2.1.1).
Not all traditional boilers are modulating, but the measurements of efficiency at 60/80 show the same trend as for condensing boilers. We have no data for traditional boilers at Pmin (30/50).

On the figure we have kept the value obtained at Pmax for the sake of comparison. The following observations can be made:
• There is a much larger variation between boilers when looking at the efficiency at Pmin compared to efficiency at Pmax. This is an important point as the boilers are mostly working close to Pmin, and this means that **there is a real difference in real-life efficiency of appliances.** Again, this is not reflected by the ErP regulation.

![Graph showing evolution of gas boiler efficiency](image)

• The efficiency at Pmax 60/80 is always higher or equal to the efficiency at Pmin for the same temperature set. This can be explained by two reasons:
  1. The fact that not all modulating boilers have an optimized air/gas system, and the air excess is on average higher at Pmin resulting in lower efficiency.
  2. The fact that fixed standby loss of e.g. 100 W will have a stronger share of losses at Pmin compared to Pmax.
This is not true anymore for the values measured at Pmin 30/50 as seen above.

c) Nominal part-load efficiency evolution
The part-load efficiencies show a rather similar picture.

d) Statistics on nominal efficiency at full and part load

The following table indicates the average of efficiencies measured under the different test conditions for:

- Traditional boilers
- Condensing boilers before 1996, we could call first generation
- Condensing boilers after 1996, we could call second generation

The limit between first and second generation is defined in the next figure showing that 1996 is a turning point when looking at full-load efficiency at Pmax, and this is more or less valid for other testing points.

However, further progress where made leading to improved annual efficiencies (partly due to improvement of hot-water efficiency for example). Therefore, further in this report we have refined the segmentation to take into account those improvements and have used 3 categories for condensing boilers:

- 1990-1996 Early (=first generation)
- 1997-2009 Transition (=second generation1)
- 2010-2015 Latest (=second generation2)
If looking even more in detail, we can look at the evolution of part load (e.g. previous graph, "Evolution of gas boiler efficiency, part load. Condensing"), and we see that even if there is no increase of efficiency in general, there are some lower efficiency boilers in the period < 2010. Combined with an increase of hot water efficiency it, therefore, makes sense to consider more sub-categories when looking at annual efficiency (see section 3.9).
The figure above gives a visual picture of the data from the table. It shows among other things that most of the progress for the second generation of condensing boilers is achieved on increased efficiency at high temperature for full-load and for part-load efficiencies. Probably on the efficiency at $P_{min}$ as well, but the data at $P_{min}$ for the first condensing boilers are not included in the database we have been working with (those boilers were either not modulating, or no tests were made at $P_{min}$).

The quantitative effect of various parameters is discussed in the following.

Water temperature effect (in % abs. of efficiency) (value of the table calculated for 10 K water temperature avg. variation)

<table>
<thead>
<tr>
<th>Avg water temp. (from-&gt;to)</th>
<th>50-&gt;70</th>
<th>40-&gt;50</th>
<th>40-70</th>
<th>33-&gt;50</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temp. effect</td>
<td>P_{max}</td>
<td>P_{max}</td>
<td>P_{min}</td>
<td>30%</td>
</tr>
<tr>
<td>Traditional</td>
<td>0,5</td>
<td></td>
<td></td>
<td>0,9</td>
</tr>
<tr>
<td>Condensing before 1996</td>
<td>2,0</td>
<td>5,1</td>
<td>2,4</td>
<td></td>
</tr>
<tr>
<td>Condensing after 1996</td>
<td>1,9</td>
<td>3,2</td>
<td>3,0</td>
<td>4,0</td>
</tr>
</tbody>
</table>

Absolute variation % of net efficiency for a variation of 10 K of water temperature
The water temperature effect depends on the type of boiler, the load and the range of temperature considered (below or above the dew point).

- **Range of water temperature**: For condensing second-generation boilers below the dew point the effect of water temperature is about 3 %-point of efficiency (at Pmax or Pmin) for each 10 K variation of water temperature. Above the dew point, the value, of course, is lower: 2% for the same dT of 10 K and only 0.5% for traditional boilers (supposed to be linear). At 30%, the effect of temperature is increasing for both the traditional and second-generation condensing boilers.

- **Load**: The effect of the temperature is depending on the load as well. For all boiler types, the effect of temperature is larger at 30% load. This is especially true for the condensing second-generation boilers.

e) **Standby losses**

The relative (to nominal max. heat input) standby loss of boilers has decreased by a factor 2 over the last 25 years, due to better insulation of appliances. The present average loss is about 0.3% of the nominal max. heat input of the boiler (measured with dT = 30K).

The relatively large dispersion of data on the figure is due both to differences in standby loss and in boiler nominal heat input. Losses do not have a linear dependency of the nominal heat input.

The absolute average value of losses are about 60 W for a boiler today (dT = 30K). For a different water/air temperature difference the equation $SBY = Kd^n$ is generally used.
2.3.2 Nominal hot water heating efficiency

Efficiency data (per boiler type)

Instantaneous boilers have a higher efficiency, as there are no water tank losses. However, a new generation of boilers with small and very well insulated tanks can match the efficiencies obtained with instantaneous appliances.

As seen on the figure, when looking at the whole period 1990-2015, there is no obvious correlations between the hot-water efficiency and the tank size,
but clearly small buffer tanks brings efficiency to quite high values of efficiency.

Analysis (evolution of nominal hot water efficiency of gas boilers since 1990)

There is a clear and positive evolution of hot-water efficiency. The improvement of hot-water efficiency is not due to changes in the size of the water tank for the tested boilers.
2.3.3 Nominal emissions (NO$_x$, CO)

The evolution of emissions of gas boilers since 1990 shows a sudden improvement in the 2000s with the introduction of a label on the Danish market resulting in the disappearing of traditional boilers. The average ratio of emission at P$_{\text{max}}$/emission at P$_{\text{min}}$ is about 3. An extended analyse of NO$_x$ emission of installed gas boilers in Denmark was carried out in 2014 by DGC /18/.

For CO, a similar figure is found. The improvements at P$_{\text{min}}$ are very important, and the average ratio of emission at P$_{\text{max}}$/emission at P$_{\text{min}}$ is about 16 (very high value due to extremely low CO for some boilers). At the
same time it seems that emission of CO at Pmax has not changed very much through the year.

If we look at the last 15 years only, the average emissions for boilers installed since 2000 are as follows:
• NO\textsubscript{x} at Pmax 60 mg/kWh
• NO\textsubscript{x} at Pmin 27 mg/kWh
• CO at Pmax 66 mg/kWh
• CO at Pmin 9 mg/kWh

2.3.4 Electricity consumption

The main evolutions on electricity consumption of boilers are the following
• An overall decrease of pump consumption
• The introduction of modulating pumps
• The decrease of standby consumption

The combined effect of these improvements is clearly impacting the annual electricity consumption (see below).
3 Annual efficiency and other annual performances of boilers

3.1 Introduction of annual efficiency

As seen in section 2, the efficiency of a boiler depends on water temperature and load. Both parameters depend on the installation. Therefore, once installed, the efficiency of the boiler may differ from the nominal efficiency measured in the laboratory and will depend on operating conditions. Especially the design of the water circuit distribution and emitters (radiators, convectors, floor heating, etc.) and the heat demand will have an influence.

Therefore, in real situations, the efficiency of the same boiler can be different from one installation to another. For that reason, annual efficiency calculation methods and models have been developed and validated.

DGC has been involved in the development of the model BOILSIM /1/. The model was validated through field test /15/, and DGC has been using the model to calculate annual efficiencies of gas boilers under the Danish climate and installation conditions.

3.2 BOILSIM

BOILSIM is an EU method for the calculation of the seasonal (annual) efficiency of domestic boilers /1/. A consortium of about 15 partners (test and research laboratories, manufacturers) developed the method starting already in 1994. BOILSIM’s main target is to allow a fair comparison of boilers on the basis of the annual efficiency, taking into account the installation and climate influence. It was in a first stage dedicated to a "labelling" application.

The work started with heating function only /10/. The hot water production function then was developed and implemented in two stages /11/, /12/. Already in 1996, the opportunity of building a "replacement" module in BOILSIM appeared: The addition of the evaluation of the performance of older boilers on existing installation led to a precise diagnosis of the energy saving in a boiler replacement situation /13/.

In parallel with the above-described actions, a demonstration project started in Denmark between 1997 and 1998. The objective was to check BOILSIM
in a real situation. This was done by extensive tests over a heating season in fully equipped and experimental buildings at GdF Suez in Paris. As a result, a number of improvements were carried out, and the first database was created /14/. At a later stage, the method was integrated in the portal, www.boilerinfo.eu.

The BOILSIM method includes a detailed part-load model for the boiler and a simpler model for the installation design and operation conditions. Comparing boiler test results with the part-load model has shown that the boiler model compares very well with measurements.

BOILSIM model requires testing data as input. Those tests have been performed by the accredited laboratory of DGC since 1990. Boilers mostly sold on the market are generally tested, and, therefore, through DGC data it is possible to get a quite accurate view of the real performances of the boilers in Danish homes.

The annual efficiency calculated includes a constant sanitary hot water demand of 2000 kWh/year (up to 3000 kWh initially, but the value was reduced at a later stage to take into account the latest data from the market) /24/.

The annual efficiency is calculated for 3 heating demands (10000, 20000 and 30000 kWh/year) and for two types of installations (traditional and low-temperature).

The method has been used since 1990 for both oil and gas boilers, and the annual efficiency calculation was in Denmark used for the national energy labelling of gas boilers, but also the Gaspro program, a calculation tool used for choosing gas boilers.

The uncertainty in the determination of annual efficiency with background laboratory test is about 2% (accumulated uncertainty using boiler test rig).

3.3 **How to calculate annual efficiency**

A given climate can be aggregated over one year with the outdoor temperature distribution curve over the heating season (number of hours and frequency expressed in number of hours).
With Danish climate data, the heating season can so be divided (in the present case) into 13 periods of outdoor temperature ranges covering the whole heating season. For a building with a given heat demand it is possible to calculate the load (heat output needed to compensate for the losses of the building assuming a given indoor temperature). If we know the radiator size (heat distribution system size) we will for each load be able to calculate the water temperature in the heat distribution system.

This means that the simple knowledge of the

- Climate
- Building
- Distribution system

makes it possible to calculate the so-called operation conditions of a heating appliance:

- The appliance load (power to be delivered)
- The water temperature.

For the given example with a house of 20,000 kWh and a standard distribution system at Tout = -6 °C the load is about 6 kW, and the average water temperature is 60 °C (traditional installation).
Determination of operational parameters in a heating installation

The load and the water temperature are the main boiler parameters that will be determining the boiler heating efficiency.

So if we can properly assess the part-load efficiency for all operating conditions, we can aggregate the results over the whole heating season and end up with the annual efficiency.
3.4 Calculating boiler efficiency for any load and any temperature

20 years ago, DGC started with an extended measuring programme consisting of measuring boiler efficiencies for a large number of water temperatures and loads. An extended test program was carried out, and efficiency was measured in the laboratory under different operational conditions where the load, the water temperature and the flow are varying. Loads included 1, 2, 4, 8 kW, full load at Pmax and Pmin, 30%, some for different water temperatures. It was in that way possible to interpolate between test results to get the needed efficiency at the needed operating conditions.

But the procedure was replaced after a 3-year development of a model (BOILSIM) taking into account the dynamic behaviour of the boiler. The work was carried out by a European consortium of experts and used by a number of partners including DGC. More information on BOILSIM is given in annex2.

<table>
<thead>
<tr>
<th>Heating</th>
<th>max 70ºC</th>
<th>max 50ºC</th>
<th>max 40ºC</th>
<th>min 70ºC</th>
<th>min 40ºC</th>
<th>30% 50ºC</th>
<th>30% 33ºC</th>
<th>50ºC</th>
<th>G20</th>
</tr>
</thead>
<tbody>
<tr>
<td>Return temperature [°C]</td>
<td>59,8</td>
<td>40,0</td>
<td>30,1</td>
<td>59,7</td>
<td>30,0</td>
<td>47,0</td>
<td>30,2</td>
<td>40,0</td>
<td></td>
</tr>
<tr>
<td>Flow temperature [°C]</td>
<td>79,6</td>
<td>60,5</td>
<td>50,7</td>
<td>79,8</td>
<td>49,7</td>
<td>52,8</td>
<td>36,1</td>
<td>60,3</td>
<td></td>
</tr>
<tr>
<td>Net heat input [kW]</td>
<td>24,0</td>
<td>24,2</td>
<td>24,6</td>
<td>5,7</td>
<td>6,1</td>
<td>6,3</td>
<td>6,5</td>
<td>23,5</td>
<td></td>
</tr>
<tr>
<td>Heat output [kW]</td>
<td>23,2</td>
<td>24,6</td>
<td>25,9</td>
<td>5,6</td>
<td>6,3</td>
<td>6,4</td>
<td>7,0</td>
<td>23,9</td>
<td></td>
</tr>
<tr>
<td>Net efficiency [%]</td>
<td>96,9</td>
<td>101,4</td>
<td>105,5</td>
<td>98,2</td>
<td>103,5</td>
<td>101,3</td>
<td>107,5</td>
<td>101,8</td>
<td></td>
</tr>
<tr>
<td>Efficiency uncertainty [% rel.]</td>
<td>1,5</td>
<td>1,5</td>
<td>1,7</td>
<td>1,8</td>
<td>2,1</td>
<td>2,1</td>
<td>2,1</td>
<td>1,5</td>
<td></td>
</tr>
<tr>
<td>Flue gas temperature [°C]</td>
<td>68</td>
<td>55</td>
<td>47</td>
<td>64</td>
<td>43</td>
<td>48,3</td>
<td>32</td>
<td>54</td>
<td></td>
</tr>
<tr>
<td>CO2 [vol-%]</td>
<td>9,2</td>
<td>9,3</td>
<td>9,3</td>
<td>7,6</td>
<td>7,9</td>
<td>8,0</td>
<td>8,0</td>
<td>8,7</td>
<td></td>
</tr>
<tr>
<td>Flue gas loss [% of heat input]</td>
<td>2,3</td>
<td>1,6</td>
<td>1,0</td>
<td>2,6</td>
<td>1,1</td>
<td>1,4</td>
<td>0,5</td>
<td>1,6</td>
<td></td>
</tr>
<tr>
<td>Condensate flow [l/h]</td>
<td>0,0</td>
<td>1,1</td>
<td>2,5</td>
<td>0,0</td>
<td>0,5</td>
<td>0,3</td>
<td>0,8</td>
<td>1,2</td>
<td></td>
</tr>
<tr>
<td>Ambient temperature [°C]</td>
<td>23,6</td>
<td>23,4</td>
<td>24,3</td>
<td>23,6</td>
<td>23,2</td>
<td>23,0</td>
<td>22,5</td>
<td>23,2</td>
<td></td>
</tr>
<tr>
<td>Ambient pressure [mbar]</td>
<td>1005</td>
<td>1005</td>
<td>1011</td>
<td>1005</td>
<td>1008</td>
<td>1007,5</td>
<td>1007</td>
<td>1005</td>
<td></td>
</tr>
<tr>
<td>Humidity [g/kg]</td>
<td>8,7</td>
<td>8,0</td>
<td>9,3</td>
<td>8,2</td>
<td>8,3</td>
<td>8,3</td>
<td>7,4</td>
<td>7,9</td>
<td></td>
</tr>
<tr>
<td>NOx [mg/kWh]</td>
<td>87</td>
<td>89</td>
<td>81</td>
<td>19</td>
<td>21</td>
<td>23</td>
<td>21</td>
<td>67</td>
<td></td>
</tr>
<tr>
<td>NOx uncertainty [% rel.]</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>13</td>
<td>12</td>
<td>10</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>CO [mg/kg]</td>
<td>124</td>
<td>128</td>
<td>115</td>
<td>3</td>
<td>5</td>
<td>5</td>
<td>4</td>
<td>91</td>
<td></td>
</tr>
<tr>
<td>CO uncertainty [% rel.]</td>
<td>8</td>
<td>7</td>
<td>4</td>
<td>0</td>
<td>39</td>
<td>32</td>
<td>39</td>
<td>7</td>
<td></td>
</tr>
</tbody>
</table>

Example of DGC's present test programme (heating efficiency) for a gas boiler

The standard test programme of DGC has been simplified, but still includes a high number of measurements that are used to set up the parameters of the boiler model and to control that there is no major deviation between part-load efficiency tested on the boiler compared to calculated values.
Example of test compared to calculation with model

<table>
<thead>
<tr>
<th>Boiler</th>
<th>Temp</th>
<th>Measured</th>
<th>Calculated</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Net Eff. %</td>
<td>Net Eff. %</td>
<td>%</td>
</tr>
<tr>
<td>Pmax</td>
<td>60/80 °C</td>
<td>98,0</td>
<td>98,0</td>
<td>0,0</td>
</tr>
<tr>
<td>Pmax</td>
<td>40/60 °C</td>
<td>100,4</td>
<td>100,7</td>
<td>0,3</td>
</tr>
<tr>
<td>Pmax</td>
<td>30/50 °C</td>
<td>103,5</td>
<td>103,5</td>
<td>0,0</td>
</tr>
<tr>
<td>Pmin</td>
<td>60/80 °C</td>
<td>98,2</td>
<td>96,3</td>
<td>-1,9</td>
</tr>
<tr>
<td>30%</td>
<td>30/36 °C</td>
<td>107,4</td>
<td>106,4</td>
<td>-1,0</td>
</tr>
<tr>
<td>Pmin</td>
<td>30/50 °C</td>
<td>106,1</td>
<td>106,6</td>
<td>0,5</td>
</tr>
<tr>
<td>30%</td>
<td>47/53 °C</td>
<td>100,5</td>
<td>100,8</td>
<td>0,3</td>
</tr>
</tbody>
</table>

We know that today the differences observed are within the uncertainties of measurement.

The details of the model can be found in the publications following the project (/10/ Annual efficiency calculation method for domestic boilers. SAVE Contract XVII/4.1031/93-008).

The BOILSIM model was compared and validated against measurement under real conditions (/5/ Field test BOILSIM GdF Suez).

Further work using service reports from the distribution company HMN Naturgas is presented and discussed in section 4.

3.5 Hot water

The hot water efficiency was also subject to developments in order to include it in the calculation, and it is integrated in a simple way. Test data for hot water are carried out for a given standard tapping pattern, and the results are combined with the heating efficiency (weighting of the two efficiencies with the corresponding heat demands)

3.6 More about annual efficiency

1) System boundaries

It is important to define clearly the actual system boundaries when discussing efficiency. In the present document, the efficiency discussed is the efficiency measured directly at the outlet of the boiler. Other losses
(distribution, control etc.) depend on the installation configuration, user behaviour etc. and not so much the boiler.

System boundaries for the definition of boiler efficiency (in orange around the boiler)

This is developed further in section 4.2 as it is often a source of misunderstanding.

Note that the pump of the boiler is not accounted for in the energy balance done to calculate the boiler efficiency (see section 2.2.2).

Furthermore, the annual efficiency method used in this document uses the hypothesis that the boiler is installed in an unheated room (this means that case losses are real losses).

2) What are the parameters that are not included in the annual efficiency given?

The annual efficiency given is the efficiency “out of the boiler”; it does not account for imperfections of the system like for instance:

- Control system ability to bring a stable/constant temperature in the space to be heated
- Possible heat stratification in rooms
Note that the above points are not depending on the heat source and will bring the same impact on efficiency as other heating technologies.

3.7 Annual emissions and annual electricity consumption

Annual emissions and annual electricity consumption are calculated according to the same principle as for efficiency: The year is divided into periods for which we calculate the load, and for each we calculate the corresponding emissions and electricity consumption, taking into account the operational parameters’ influence (water temperature, etc.), when relevant.

In 2014, DGC prepared an extensive study of the existing population of appliances installed in Denmark (Evaluation of the NOx emissions of the Danish population of gas boilers below 120 kW) /18/. Most of the results of this section originate from the report given.

For the sake of this study, DGC also developed a calculation method very similar to the one used for the annual efficiency: The following figure explains the principle used:

- In the modulation range, these emissions are determined by interpolation between the emissions measured at Pmin, 60/80°C and Pmax, 60/80°C.
• Below the modulation range, we suppose that the boiler is start-stopping at Pmin

The emission of modulating boilers in the range of the modulation will depend on the load and the temperature. The applicable emission is calculated by linear interpolation between test points obtained at Pmin and Pmax for the two temperature sets tested. When not known, default values obtained with our existing test statistics are taken.

The graph above shows how we calculate emissions for Pi, Ti (with experimental values (line calculated with two test points)). First, emissions are calculated for the given temperature at Pmax and Pmin. Then, the emission for the given load is interpolated between the two points. We suppose here that NOx varies with temperature and load in a linear way.

The work done earlier /18/ was carried out on a population of 100 appliances (so not entirely the database extended for the sake of the present project). The appliances were classified according to the following segmentation:

C & D  Floor standing and boiler with tank integrated (atm. burner)
E & F  Trad. boiler (atm. burner)
G & H  Trad. boiler gas/air control
3.8 **What main parameters are influencing annual efficiency?**

- The design **radiator installation** plays an important role for the performance of appliances: the more radiators/convectors, the lower the water temperature in the distribution system and so the higher the efficiency of the boiler.

Since 2005 in Denmark (Building regulation BR2005), the design radiator system temperature is 55 °C for all new buildings. However, installers have been educated to design distribution systems for condensing boilers, and therefore such low temperature is not unusual for houses built before the regulation entered in force in 2005 /25/

Furthermore, existing houses subject to additional thermal insulation will see their distribution system “oversized” as a consequence of the insulation, and this will lower the average water temperature in radiators as well.

The next two tables show examples of operating conditions of a boiler installed in a 20,000 kWh (annual heat demand) house and with an installation according to the present rules in Denmark (Twater average = 55 °C) and “old fashioned” radiator installation (here designed with high water temperature in the radiators 60-80).

---

### IMPORTANT NOTE

In the following we consider

- **TT** = **Traditional temperature** here designed with high water temperature in the radiators 60-80 °C
- **LT** = **Low temperature** here designed with water temperature Twater average = 55 °C
- **MX** = **Mixed** Can be either:
  - An installation with a mixture of both of the above (old radiator system with floor heating). In this case an equal share of LT & TT is assumed.
- Or an existing Traditional Temperature installation in a renovated house subject to insulation (reducing the heat demand and so the water temperature)
- Or an existing Traditional Temperature installation where the user has extended the radiator system.

Note that the above definitions are originating from DGC's early work in the 90s. In order not to bring confusion with the existing publications and calculation results we have used the definition from the 90s despite the fact that the current rules for designing installation have evolved (see the discussion in 6.3).

Both tables based on the Danish climate show that the return temperature to the boiler is below the condensing dew point for installation with variable flow.

If we assume a constant flow, the return temperature is increasing, but still it is below the dew point most of the time.

If the radiator system is oversized, the return temperature decreases.

<table>
<thead>
<tr>
<th>Heating</th>
<th></th>
<th>OPERATING CONDITIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>annual heat demand (kWh)</td>
<td>20000</td>
<td></td>
</tr>
<tr>
<td>degree hours</td>
<td>72247</td>
<td></td>
</tr>
<tr>
<td>reference temperature</td>
<td>17</td>
<td></td>
</tr>
<tr>
<td>design temperature</td>
<td>-12</td>
<td></td>
</tr>
<tr>
<td>heat demand per degree hour (kW)</td>
<td>0.277</td>
<td></td>
</tr>
<tr>
<td>design radiator size (kW)</td>
<td>8.03</td>
<td></td>
</tr>
<tr>
<td>oversizing</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>design flow</td>
<td>461</td>
<td></td>
</tr>
<tr>
<td>Tflow</td>
<td>62.3</td>
<td></td>
</tr>
<tr>
<td>Treturn</td>
<td>47.5</td>
<td></td>
</tr>
<tr>
<td>Troom</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>constant flow?</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>pump modulation range</td>
<td>912</td>
<td></td>
</tr>
<tr>
<td>n</td>
<td>1.2</td>
<td></td>
</tr>
<tr>
<td>heating season</td>
<td>288</td>
<td></td>
</tr>
</tbody>
</table>

Example of operating conditions for a 55 °C (avg.) radiator installation. No radiator oversizing.
Example of operating conditions for a 70 °C (avg.) radiator installation. No radiator oversizing.

- The **correct adjustment of boilers** (CO₂). Most condensing boilers with premix burners can be adjusted by changing the air-to-gas ratio so it fits with manufacturer's instructions. The incorrect adjustment will lead to additional flue gas losses and possibly safety issues (CO).

  However, the data available shows that Danish boilers are well installed and well-adjusted, and that the adjustment is rather stable as shown by reporting from maintenance reports (see section 4).

- The **maintenance of installations** can be important for the safety of the system, but it has not a large impact on the efficiency of it, as in contrast to other fuels (e.g. fuel oil) gas combustion is producing a very small amount of particles that could diminish the performance of heat exchangers.

- **Heat demand/hot-water demand.** The hot water is produced with a lower efficiency compared to the heat. The more hot water demand proportionally to the heat demand, the lower the average efficiency (and the other way round).

  The following table shows how average boiler efficiency will vary with the heat demand with **constant hot-water demand**.
The table above is applicable for different houses/users with different heat demands, but with a heat distribution system adapted to their demand. It is not applicable for a single user charging his heat demand, unless he also adapts the heat distribution system accordingly.

Today’s average heat demand is closer to 18,000 kWh/year, but 20,000 kWh has been used through the years to have a stable reference and basis for comparison with existing data.

- **Hot water demand.** As mentioned above, sanitary hot water is generally produced with lower efficiency compared to heating, due to additional losses (as for example storage tank losses). Obviously, combining efficiencies for hot-water production and heating production will result in a figure of efficiency in-between both values obtained for hot water and heating. The exact value will depend on the respective demands for hot water and heating.
The following table shows an example of how the hot-water efficiency varies with the hot water demand.

**Hot water production: summer efficiency (boiler BA05)**

<table>
<thead>
<tr>
<th>Hot water demand [kWh]</th>
<th>1000</th>
<th>2000</th>
<th>3000</th>
<th>4000</th>
<th>5000</th>
<th>6000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Net Efficiency [%]</td>
<td>62</td>
<td>75</td>
<td>81</td>
<td>84</td>
<td>86</td>
<td>88</td>
</tr>
</tbody>
</table>

See more extensive data about hot water production in section 2.3.2.

### 3.9 Overall result of annual efficiency calculation for heating alone (without hot water)

**Important note:** The efficiencies given in this report may be slightly different from previous references and communications (as for instance /6/), as the number of boilers used for making statistics are quite different. The present report includes almost 200 boilers, which is more boilers than any previous investigations. The present data will also change in the future when more boilers are added.

a) **Overall evolution. Annual efficiency for annual heat demand 20,000 kWh.**

The figure gives a visual impression of the evolution of annual efficiency through the years (graph made with all boilers ranked in chronology).
The next figure is built with the same data, but as a direct linear function of the year. The graph shows the interesting changes that occurred in 2004 and followed the introduction of the boiler labelling system in Denmark.
b) Statistics. Net annual efficiency for various heat demands and heat
distribution systems (without hot water).

In section 2.3 we identified two generations of condensing boilers based on
nominal efficiency (before and after 2006). Below we introduce an
additional segmentation (after 2010) to take into account further evolutions
(e.g. hot-water efficiency has increased significantly between 1996 and
2015).

We have here carried out calculations over 3 periods and have differentiated
between condensing and traditional:

Condensing boilers
- Early: 1990-1996 (first generation condensing)
- Transition: 2000-2010 (second generation condensing)
- Latest: 2010-2015) (second generation condensing still)

Traditional boilers
- Early: 1990-1996
- Transition: 2000-2010+ (‘‘2010+’’ because we have few traditional
boilers after 2010).

Net annual efficiency for various heat demands, distribution systems.
( TT= Traditional temperature, LT = Low temperature)
<table>
<thead>
<tr>
<th>Boiler</th>
<th>Heat demand (kWh)</th>
<th>TT 10.000</th>
<th>LT 10.000</th>
<th>TT 20.000</th>
<th>LT 20.000</th>
<th>TT 30.000</th>
<th>LT 30.000</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>AVG</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trad</td>
<td>1990-1996 Early</td>
<td>81,7</td>
<td>83,6</td>
<td>84,5</td>
<td>85,6</td>
<td>85,6</td>
<td>86,4</td>
</tr>
<tr>
<td>Trad</td>
<td>1997-2009 Transition</td>
<td>82,9</td>
<td>84,8</td>
<td>86,1</td>
<td>87,1</td>
<td>87,2</td>
<td>87,9</td>
</tr>
<tr>
<td>Cond</td>
<td>1990-1996 Early</td>
<td>91,8</td>
<td>96,8</td>
<td>96,3</td>
<td>100,1</td>
<td>97,8</td>
<td>101,2</td>
</tr>
<tr>
<td>Cond</td>
<td>1997-2009 Transition</td>
<td>95,7</td>
<td>100,2</td>
<td>99,5</td>
<td>103,1</td>
<td>100,7</td>
<td>103,7</td>
</tr>
<tr>
<td>Cond</td>
<td>2010-2015 Latest</td>
<td>98,2</td>
<td>102,8</td>
<td>102,4</td>
<td>105,6</td>
<td>103,6</td>
<td>106,0</td>
</tr>
<tr>
<td><strong>MIN</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trad</td>
<td>1990-1996 Early</td>
<td>71,9</td>
<td>74,5</td>
<td>76,4</td>
<td>77,8</td>
<td>78,0</td>
<td>79,0</td>
</tr>
<tr>
<td>Trad</td>
<td>1997-2009 Transition</td>
<td>77,3</td>
<td>79,5</td>
<td>80,3</td>
<td>81,4</td>
<td>81,2</td>
<td>82,1</td>
</tr>
<tr>
<td>Cond</td>
<td>1990-1996 Early</td>
<td>86,9</td>
<td>92,6</td>
<td>91,9</td>
<td>95,8</td>
<td>93,5</td>
<td>97,4</td>
</tr>
<tr>
<td>Cond</td>
<td>1997-2009 Transition</td>
<td>90,3</td>
<td>94,8</td>
<td>95,6</td>
<td>97,0</td>
<td>96,8</td>
<td>97,9</td>
</tr>
<tr>
<td>Cond</td>
<td>2010-2015 Latest</td>
<td>95,4</td>
<td>99,5</td>
<td>100,1</td>
<td>103,7</td>
<td>102,0</td>
<td>104,1</td>
</tr>
<tr>
<td><strong>MAX</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trad</td>
<td>1990-1996 Early</td>
<td>88,2</td>
<td>90,2</td>
<td>91,7</td>
<td>92,7</td>
<td>92,7</td>
<td>93,5</td>
</tr>
<tr>
<td>Trad</td>
<td>1997-2009 Transition</td>
<td>90,0</td>
<td>92,6</td>
<td>93,7</td>
<td>95,1</td>
<td>94,9</td>
<td>95,8</td>
</tr>
<tr>
<td>Cond</td>
<td>1990-1996 Early</td>
<td>95,8</td>
<td>102,7</td>
<td>103,5</td>
<td>107,1</td>
<td>105,4</td>
<td>107,6</td>
</tr>
<tr>
<td>Cond</td>
<td>1997-2009 Transition</td>
<td>101,1</td>
<td>106,3</td>
<td>104,2</td>
<td>108,2</td>
<td>105,6</td>
<td>109,0</td>
</tr>
<tr>
<td>Cond</td>
<td>2010-2015 Latest</td>
<td>102,3</td>
<td>106,7</td>
<td>104,9</td>
<td>108,4</td>
<td>105,8</td>
<td>108,9</td>
</tr>
</tbody>
</table>
3.10 Overall result of annual efficiency calculation with hot water (2,000 kWh/year)

a) Overall evolution. Annual efficiency for annual heat demand 20,000 kWh.
b) Statistics. Net annual efficiency for various heat demands and heat distribution systems.

Again, we have here carried out calculations over 3 periods and for condensing and traditional boilers separately:

**Net annual efficiency** for various heat demands, distribution systems.

(*TT* = Traditional temperature, *LT* = Low temperature)

<table>
<thead>
<tr>
<th>Distribution system</th>
<th>Heat demand (kWh)</th>
<th>TT</th>
<th>LT</th>
<th>TT</th>
<th>LT</th>
<th>TT</th>
<th>LT</th>
</tr>
</thead>
<tbody>
<tr>
<td>AVG</td>
<td>10,000</td>
<td>10,000</td>
<td>20,000</td>
<td>20,000</td>
<td>30,000</td>
<td>30,000</td>
<td></td>
</tr>
<tr>
<td>1990-1996 Early</td>
<td>76,0</td>
<td>77,4</td>
<td>80,8</td>
<td>81,7</td>
<td>82,8</td>
<td>83,4</td>
<td></td>
</tr>
<tr>
<td>1997-2009+ Transition</td>
<td>78,3</td>
<td>79,7</td>
<td>83,0</td>
<td>83,8</td>
<td>84,9</td>
<td>85,5</td>
<td></td>
</tr>
<tr>
<td>1990-1996 Early</td>
<td>85,8</td>
<td>89,3</td>
<td>92,1</td>
<td>95,3</td>
<td>94,8</td>
<td>97,7</td>
<td></td>
</tr>
<tr>
<td>1997-2009 Transition</td>
<td>90,7</td>
<td>94,0</td>
<td>96,1</td>
<td>99,2</td>
<td>98,2</td>
<td>100,9</td>
<td></td>
</tr>
<tr>
<td>2010-2015 Latest</td>
<td>92,4</td>
<td>95,8</td>
<td>98,5</td>
<td>101,2</td>
<td>100,7</td>
<td>102,9</td>
<td></td>
</tr>
<tr>
<td>MIN</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1990-1996 Early</td>
<td>62,5</td>
<td>64,1</td>
<td>69,9</td>
<td>71,0</td>
<td>73,1</td>
<td>74,0</td>
<td></td>
</tr>
<tr>
<td>1997-2009+ Transition</td>
<td>73,0</td>
<td>74,5</td>
<td>77,4</td>
<td>78,3</td>
<td>79,1</td>
<td>79,9</td>
<td></td>
</tr>
<tr>
<td>1990-1996 Early</td>
<td>76,2</td>
<td>79,0</td>
<td>84,1</td>
<td>87,1</td>
<td>87,7</td>
<td>91,0</td>
<td></td>
</tr>
<tr>
<td>1997-2009 Transition</td>
<td>78,3</td>
<td>80,6</td>
<td>86,8</td>
<td>89,5</td>
<td>90,8</td>
<td>93,7</td>
<td></td>
</tr>
<tr>
<td>2010-2015 Latest</td>
<td>88,0</td>
<td>90,9</td>
<td>95,6</td>
<td>98,0</td>
<td>98,5</td>
<td>100,1</td>
<td></td>
</tr>
<tr>
<td>MAX</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1990-1996 Early</td>
<td>84,7</td>
<td>86,4</td>
<td>89,4</td>
<td>90,3</td>
<td>91,0</td>
<td>91,7</td>
<td></td>
</tr>
<tr>
<td>1997-2009+ Transition</td>
<td>84,5</td>
<td>85,6</td>
<td>87,9</td>
<td>88,6</td>
<td>89,4</td>
<td>89,7</td>
<td></td>
</tr>
<tr>
<td>1990-1996 Early</td>
<td>90,5</td>
<td>95,0</td>
<td>99,0</td>
<td>102,0</td>
<td>102,0</td>
<td>104,0</td>
<td></td>
</tr>
<tr>
<td>1997-2009 Transition</td>
<td>96,0</td>
<td>100,0</td>
<td>104,0</td>
<td>104,0</td>
<td>103,0</td>
<td>106,0</td>
<td></td>
</tr>
<tr>
<td>2010-2015 Latest</td>
<td>97,0</td>
<td>100,0</td>
<td>101,0</td>
<td>104,0</td>
<td>103,0</td>
<td>105,3</td>
<td></td>
</tr>
</tbody>
</table>

**3.11 Detailed annual efficiency calculation for Danish average houses**

This section gives practical tools (figures and tables) in order to determine the average annual efficiency of the latest gas boilers available on the Danish market. The section is useful, if you need to get an idea of annual efficiency of modern boilers in various common installations. For more
specific calculation we recommend to use the Gaspro program (http://www.dgc.dk/gaspro-energiberegning).
According to our latest information of Danish average houses, the heat demand is today about 18,000 kWh.
In the following we show how annual efficiency changes with the heat demand for average boilers of the most recent period (2010-2015).

HW = Hot water TT= Traditional temperature, LT = Low temperature

The above figure is generated by linear interpolation of average results obtained for 10,000 and 20,000 kWh heat demand, respectively.
The figure can be used to calculate the average efficiency of boilers (period 2010-2015) for any heat demand in the range 10,000 and 20,000 kWh and hot water demand 0 to 2,000 kWh.

Please, keep in mind:
- There is a slight uncertainty due to the method used (variations are not linear in practice)
- There are boilers with higher efficiency and lower efficiency (see figures in previous sections)
Example of use of the figure for a heat demand of 18,000 kWh (probably close to the avg. Danish house in 2015).

The figure can be used to read the efficiencies for the 4 situations:

- Without hot water – for low-temperature installations
- Without hot water – for traditional-temperature installations
- With hot water – for low-temperature installations
- With hot water – for traditional-temperature installations

The corresponding efficiencies for a heat demand of 18,000 kWh are:

- 105.1 % without hot water – for low-temperature installations
- 101.7 % without hot water – for traditional-temperature installations
- 100.2 % with hot water – for low-temperature installations
- 97.4 % with hot water – for traditional-temperature installations
The figure can be used to determine graphically any variations compared to the 4 cases. (For convenience, Annex4 shows a full A4 sheet).

**Example 1**: House with a Mixed distribution system (MX) (see 3.8). Without hot water.
Example 2: Same as above, but with hot water.

Example 3: House with low-temperature (LT) system with 1000 kWh hot water.
**Example 4:** House with traditional-temperature (TT) system with 1,000 kWh hot water.

**Example 5:** Same as above (house with traditional-temperature (TT) system with 1,000 kWh hot water), but with 19,000 kWh heat demand.
The following table can also be used in order to determine the **average** annual efficiency of the **most recent boilers** (2010-2015) under various installation conditions.

\[ HW = \text{Hot water} \quad TT = \text{Traditional temperature} \quad LT = \text{Low temperature} \quad MX = \text{Mix (see definitions in 3.8)} \]

Note that results can vary within approx. ±3% (abs.)\(^(*)\) depending on the boiler chosen

\(^(*)\) range of variation calculated for 20,000 kWh

For some applications /2/ the annual efficiency is expressed **without including the loss of the water tank.**

The tank losses are discussed in the section 2.2.3

The following table is giving an evaluation of the boiler efficiency for two typical cases with a water tank of 70l and 100l with respective losses of 29 W and 38 W.

We suppose the loss is occurring during the whole year.

In the case of 2000 kWh/year hot water need, this will impact the efficiency by 1,0 to 1,6 % for the 70 l. water tank and 1,3 to 2,1% for the 100 l. water tank.

In case hot water tank losses shall not be included in the annual efficiency the following tables shall be used:

<table>
<thead>
<tr>
<th>Heat demand kWh/year</th>
<th>without HW LT</th>
<th>without HW TT</th>
<th>without HW MX</th>
<th>with 1000 kWh HW LT</th>
<th>with 1000 kWh HW TT</th>
<th>with 1000 kWh HW MX</th>
<th>with 2000 kWh HW LT</th>
<th>with 2000 kWh HW TT</th>
<th>with 2000 kWh HW MX</th>
</tr>
</thead>
<tbody>
<tr>
<td>14000</td>
<td>104,0</td>
<td>100,0</td>
<td>102,0</td>
<td>101,0</td>
<td>97,5</td>
<td>99,3</td>
<td>98,1</td>
<td>94,9</td>
<td>96,5</td>
</tr>
<tr>
<td>15000</td>
<td>104,3</td>
<td>100,4</td>
<td>102,3</td>
<td>101,4</td>
<td>98,0</td>
<td>99,7</td>
<td>98,6</td>
<td>95,5</td>
<td>97,1</td>
</tr>
<tr>
<td>16000</td>
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<td>100,8</td>
<td>102,7</td>
<td>101,8</td>
<td>98,5</td>
<td>100,2</td>
<td>99,1</td>
<td>96,1</td>
<td>97,6</td>
</tr>
<tr>
<td>17000</td>
<td>104,8</td>
<td>101,3</td>
<td>103,0</td>
<td>102,3</td>
<td>99,0</td>
<td>100,6</td>
<td>99,7</td>
<td>96,8</td>
<td>98,2</td>
</tr>
<tr>
<td>18000</td>
<td>105,1</td>
<td>101,7</td>
<td>103,4</td>
<td>102,7</td>
<td>99,5</td>
<td>101,1</td>
<td>100,2</td>
<td>97,4</td>
<td>98,8</td>
</tr>
<tr>
<td>19000</td>
<td>105,4</td>
<td>102,1</td>
<td>103,7</td>
<td>103,1</td>
<td>100,0</td>
<td>101,5</td>
<td>100,7</td>
<td>98,0</td>
<td>99,3</td>
</tr>
<tr>
<td>20000</td>
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<td>102,5</td>
<td>104,1</td>
<td>103,5</td>
<td>100,5</td>
<td>102,0</td>
<td>101,3</td>
<td>98,6</td>
<td>99,9</td>
</tr>
<tr>
<td>21000</td>
<td>106,0</td>
<td>102,9</td>
<td>104,4</td>
<td>103,9</td>
<td>101,0</td>
<td>102,5</td>
<td>101,8</td>
<td>99,2</td>
<td>100,5</td>
</tr>
<tr>
<td>22000</td>
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<td>104,3</td>
<td>101,6</td>
<td>102,9</td>
<td>102,3</td>
<td>99,8</td>
<td>101,0</td>
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<td>105,1</td>
<td>104,7</td>
<td>102,1</td>
<td>103,4</td>
<td>102,8</td>
<td>100,4</td>
<td>101,6</td>
</tr>
</tbody>
</table>
### 3.12 Annual NOx emissions

The method described in section 3.7 has given the following result.

<table>
<thead>
<tr>
<th>CLASS</th>
<th>Number of samples for each class and test</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pmax 60/80 °C</td>
</tr>
<tr>
<td>CD</td>
<td>10</td>
</tr>
<tr>
<td>EF</td>
<td>17</td>
</tr>
<tr>
<td>GH</td>
<td>4</td>
</tr>
<tr>
<td>I</td>
<td>5</td>
</tr>
<tr>
<td>K</td>
<td>41</td>
</tr>
<tr>
<td>L</td>
<td>24</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>CLASS</th>
<th>NOx (mg/kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pmax 60/80 °C</td>
</tr>
<tr>
<td>CD</td>
<td>119.4</td>
</tr>
<tr>
<td>EF</td>
<td>186.2</td>
</tr>
<tr>
<td>GH</td>
<td>239.3</td>
</tr>
<tr>
<td>I</td>
<td>74.5</td>
</tr>
<tr>
<td>K</td>
<td>94.3</td>
</tr>
<tr>
<td>L</td>
<td>58.2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>STD</th>
<th>Pmax 60/80 °C</th>
<th>Pmax 40/60 °C</th>
<th>Pmin 60/80 °C</th>
<th>Pmin 40/60 °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>CD</td>
<td>77.2</td>
<td>67.9</td>
<td>52.0</td>
<td></td>
</tr>
</tbody>
</table>
The resulting annual emissions are shown on the following figure for a heat demand of 10,000 kWh:

For other heat demands the figures are shown in the following table:

<table>
<thead>
<tr>
<th>Class</th>
<th>Heat Input (kWh):</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10000</td>
</tr>
<tr>
<td>A</td>
<td>0.91</td>
</tr>
<tr>
<td>CD</td>
<td>1.26</td>
</tr>
<tr>
<td>EF</td>
<td>1.77</td>
</tr>
<tr>
<td>GH</td>
<td>2.47</td>
</tr>
<tr>
<td>K</td>
<td>0.83</td>
</tr>
<tr>
<td>I</td>
<td>1.02</td>
</tr>
<tr>
<td>L</td>
<td>0.42</td>
</tr>
</tbody>
</table>

Average annual NO$_x$ emissions by class as function of the heat input
The vast majority of old appliances (class CD; EF; GH) are replaced by the newest appliances (Class I, K, L) with the lowest emissions. Note that some of these old appliances are now banned from the market (non-condensing boilers).

### 3.13 Annual CO emissions

CO emissions of boilers are more related to safety than to environment. All appliances tested have to respect the safety regulations in force (GAD), and all do so. Therefore, we have not performed statistics on CO emissions of gas boilers, but this is possible when relevant/needed.

### 3.14 Annual electricity consumption

**a) Overall evolution. Annual efficiency for annual heat demand 20,000 kWh.**

The figure shows the evolution of electricity consumption (base 20,000 kWh/year heat + 2,000 kWh hot water). The figure indicates the consumption in case the pumps are always in operation (Elmax), and the
case where the pump stops following the burner operation (Elmin) (after a given “after run time” declared by the manufacturer).

The electricity consumption has decreased quite a lot over the last decades, for the main reason that pump technology has evolved quite a lot (modulating pumps).

b) Statistics. Annual electricity consumption (in kWh) for various heat demands and periods.

<table>
<thead>
<tr>
<th>Boiler</th>
<th>Heat demand (kWh)</th>
<th>El. max</th>
<th>El. min</th>
<th>El. min</th>
<th>El. min</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trad</td>
<td>1990-1996 Early</td>
<td>651</td>
<td>502</td>
<td>568</td>
<td>588</td>
</tr>
<tr>
<td>Trad</td>
<td>1997-2009 Transition</td>
<td>790</td>
<td>515</td>
<td>557</td>
<td>592</td>
</tr>
<tr>
<td>Cond</td>
<td>1990-1996 Early</td>
<td>598</td>
<td>405</td>
<td>450</td>
<td>485</td>
</tr>
<tr>
<td>Cond</td>
<td>1997-2009 Transition</td>
<td>576</td>
<td>351</td>
<td>380</td>
<td>401</td>
</tr>
<tr>
<td>Cond</td>
<td>2010-2015 Latest</td>
<td>221</td>
<td>126</td>
<td>155</td>
<td>174</td>
</tr>
<tr>
<td>Trad</td>
<td>1990-1996 Early</td>
<td>260</td>
<td>214</td>
<td>248</td>
<td>282</td>
</tr>
<tr>
<td>Trad</td>
<td>1997-2009 Transition</td>
<td>600</td>
<td>394</td>
<td>418</td>
<td>442</td>
</tr>
<tr>
<td>Cond</td>
<td>1990-1996 Early</td>
<td>259</td>
<td>188</td>
<td>210</td>
<td>224</td>
</tr>
<tr>
<td>Cond</td>
<td>1997-2009 Transition</td>
<td>170</td>
<td>116</td>
<td>161</td>
<td>187</td>
</tr>
<tr>
<td>Cond</td>
<td>2010-2015 Latest</td>
<td>131</td>
<td>67</td>
<td>90</td>
<td>106</td>
</tr>
<tr>
<td>Trad</td>
<td>1990-1996 Early</td>
<td>1082</td>
<td>715</td>
<td>836</td>
<td>932</td>
</tr>
<tr>
<td>Trad</td>
<td>1997-2009 Transition</td>
<td>941</td>
<td>604</td>
<td>646</td>
<td>722</td>
</tr>
<tr>
<td>Cond</td>
<td>1990-1996 Early</td>
<td>920</td>
<td>695</td>
<td>836</td>
<td>883</td>
</tr>
<tr>
<td>Cond</td>
<td>1997-2009 Transition</td>
<td>1187</td>
<td>729</td>
<td>748</td>
<td>766</td>
</tr>
<tr>
<td>Cond</td>
<td>2010-2015 Latest</td>
<td>381</td>
<td>226</td>
<td>260</td>
<td>277</td>
</tr>
<tr>
<td>Trad</td>
<td>1990-1996 Early</td>
<td>12</td>
<td>14</td>
<td>14</td>
<td>11</td>
</tr>
<tr>
<td>Trad</td>
<td>1997-2009 Transition</td>
<td>17</td>
<td>17</td>
<td>17</td>
<td>16</td>
</tr>
<tr>
<td>Cond</td>
<td>1990-1996 Early</td>
<td>11</td>
<td>11</td>
<td>11</td>
<td>11</td>
</tr>
<tr>
<td>Cond</td>
<td>1997-2009 Transition</td>
<td>93</td>
<td>103</td>
<td>103</td>
<td>94</td>
</tr>
<tr>
<td>Cond</td>
<td>2010-2015 Latest</td>
<td>32</td>
<td>37</td>
<td>37</td>
<td>32</td>
</tr>
</tbody>
</table>

Annual electricity consumption is calculated as an interval Min-Max. El. Max – the maximum electricity consumption is obtained if the pumps are constantly in operation. Therefore, it is only given for 20.000 kWh heat demand as it is not very much influenced by the heat demand. The minimum electricity consumption is obtained when the pump stops during
off time of the burner (or shortly after). In this last case it depends very much on the burner operation time and so the heat demand. Therefore, we have calculated the minimum electricity consumption for 3 standard heat demands (3 last columns).
4 Discussion of the results

4.1 Are condensing boilers properly installed: Installation of condensing boilers in Denmark

As previously seen the condensation of flue gas water vapour will take place (see Section 1) in the boiler heat exchanger when its surface temperature is lower than about 60 °C.

The water from the heating system, which is heated in the boiler, must therefore have a transition temperature in the boiler, which is lower than about 60 °C, i.e. return water temperature from the dwelling radiators must be lower than about 60 °C.

This is achieved partly through legislation which ensures proper operating conditions for condensing boilers. Thus, since 1995 it has been a requirement of the Building Regulations (www.bygningsreglementet.dk). For the design of heat distribution systems, the avg. water temperature in the heating system must be 55 °C (for Tout = -12 °C). The supply and return temperatures are about 62.5 °C and about 47.5 °C, respectively.

Finally, in many newer houses floor heating is used instead of radiators, and for these plants the return temperature from the heating system is typically 30 °C.

Since condensing boilers are on the market, the installation of condensing boilers has been subject to “installation guidelines” in Denmark /25/. Moreover, procedures for correct installation are also provided by individual boiler suppliers' guidelines.

Since the coming into force of the building regulations BR2005 it has been required that all newly installed gas boilers must be condensing, and, therefore, for many the installation of condensing equipment has been routine for the last 10-15 years.

Thus, there is good reason to believe that gas boilers and gas heating systems are optimized for a good condensing operation.
4.2 Can the results obtained by calculation with models and test from laboratory be compared to “real efficiency”?

4.2.1 System boundaries

As the question of comparison of models based on laboratory test with real situation is often discussed, it is important to define first the boundaries of the system that we are talking about.

In the present report, we discuss the efficiency out of the heater (boiler), and not what occurs with the heat afterwards (see section 2.2.1). When sending the heat to the heat distribution system in the house, there will be additional losses that depend on a lot of parameters like pipe configuration (length, insulation etc.) to the radiators, the control system’s ability to maintain a constant temperature in the house, possible hydronic issues in the radiator system, user habits etc. that are altogether independent of the heater nature, as this will be the same for all kinds of central heating appliances, such as electrical heat pump or a district heating exchanger.

The boiler defined in its boundaries can be seen as a box where we inject gas, and where useful heat is produced. The difference between the input and output are losses, and here there are only two types of losses: the case loss and the flue gas loss.

About the boiler pump

Note that a gas boiler is typically sold with a pump. For the calculation of efficiency the energy balance is made with the pump not included in the system boundaries. This means that the electricity to run the pump and other components is not included in the energy balance to calculate the efficiency, nor is the heat transferred to the water by the pump. But the electricity to run the pump and other components is accounted for in the electricity consumption calculation.
As previously seen (section 2.3.1.e) case loss is quite low and represents max. 2% of the heat input in most of the cases. Moreover, if the boiler is installed in a heated room, case loss is not really a loss, as it will contribute to the space heating. The annual efficiency method used in this document is conservative on this point as the case loss is considered as loss, and therefore we use the hypothesis that the boiler is installed in an unheated room.

There is no reason why case loss should be different in a real installation compared to laboratory measurements, unless the user has removed the boiler insulation.

The flue gas loss is very much depending on the quantity of air that is burned with the gas. For modern condensing premix boilers, the air excess is given by the boiler adjustment, and manufacturers are indicating the CO₂ value in their documentation. Installers must respect the value given both at the installation phase of the boiler and at maintenance. If they do their job properly, there is no reason to think that flue gas loss in a real situation would differ from the flue gas loss measured in laboratory.
4.2.2 Are installers doing their job properly? Service on gas boilers

In the framework of a previous project aiming at assessing gas boiler efficiencies /1/, DGC checked the CO₂ values in the service reports compared to the value of DGC’s test report.

A large number of gas boilers in Denmark are covered by a regular service scheme, under which the boiler operation and safety are checked, and the boiler is adjusted if necessary. The service companies that perform this work must have authorization from the safety authorities (The Danish Safety Technology Authority) (see 5.3).

The service reports provided can differ slightly depending on the service company, but the content includes more or less the same information about the boiler operation, including a number of measured combustion values. In addition, reports include various pieces of information about the installation.

The measured combustion-related parameters are:

- Flue gas temperature
- CO₂ (%) and/or O₂ (%) in flue gas (typically measured O₂ and calculated CO₂)
- CO (ppm) in the flue gas (must be less than 1,000 ppm)
- Air temperature

Based on these measurements, the following is calculated (indicated on the service report):

- Excess air (how much air out of the necessary quantity of air for combustion, passes through the boiler)
- Flue gas loss (the amount of energy released through the chimney)
- Flue gas loss efficiency

It is estimated that the quality of the measured and calculated data is good despite the fact that many service reports do not include all above data.

Also the measurement accuracy of data in service reports is rather fine. A typical example for flue gas measurement device TESTO is giving a measurement error of ±0.2 vol.% of oxygen measurement, and ±0.5 °C, on the flue gas temperature and the combustion air temperature.
4.2.3 Results

The following table shows for about 40 different installations:

- The results of the CO₂ value of the service report with the indication of the variation of CO₂ after/before control/maintenance\(^3\)
- The results (CO₂, flue gas loss) obtained in laboratory
- The difference between laboratory/field measurement

\(^3\) Note that today installers should not adjust a boiler without knowing the actual gas quality in the grid.
Note that we have not included the flue gas temperature measured during the service, as it is systematically lower than that measured in the laboratory, most likely caused by a too short measurement period.
The two above figures demonstrate that

- There are only small variations in CO₂ before and after service, and this also means between two services. The range of variation is from -1.5 to +0.5 (difference CO₂ after, CO₂ before)
There are only small differences between the CO₂ measured in the laboratory and measurement after service. This is not a surprise, as the adjustment is made according to the manufacturer's instruction which should indicate the same CO₂. There is a single case where the deviation is 1.5%, and we do not have an explanation for it.

4.2.4 How can these differences impact the boiler efficiency?

Let us take two examples here.

To calculate the flue gas loss we need to use a gas composition. We have chosen a Danish gas composition from the 1990s (note that this will not change the following results very much)

<table>
<thead>
<tr>
<th>Component</th>
<th>Share (vol.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>H₂</td>
<td>0.00000</td>
</tr>
<tr>
<td>CO</td>
<td>0.00000</td>
</tr>
<tr>
<td>CH₄</td>
<td>0.90750</td>
</tr>
<tr>
<td>C₂H₄</td>
<td>0.00000</td>
</tr>
<tr>
<td>C₂H₆</td>
<td>0.05150</td>
</tr>
<tr>
<td>C₃H₆</td>
<td>0.00000</td>
</tr>
<tr>
<td>C₃H₈</td>
<td>0.01890</td>
</tr>
<tr>
<td>C₄H₈</td>
<td>0.00000</td>
</tr>
<tr>
<td>C₄H₁₀</td>
<td>0.00390</td>
</tr>
<tr>
<td>C₅H₁₀</td>
<td>0.00290</td>
</tr>
<tr>
<td>C₅H₁₂</td>
<td>0.00200</td>
</tr>
<tr>
<td>C₆H₁₂</td>
<td>0.00150</td>
</tr>
<tr>
<td>C₆H₁₄</td>
<td>0.00000</td>
</tr>
<tr>
<td>CO₂</td>
<td>0.00610</td>
</tr>
<tr>
<td>O₂</td>
<td>0.00000</td>
</tr>
<tr>
<td>N₂</td>
<td>0.00320</td>
</tr>
</tbody>
</table>
A premix condensing boiler installation [I3-K11] from the previous result table

<table>
<thead>
<tr>
<th>Nominal Conditions</th>
<th>60/80</th>
<th>40/60</th>
<th>30/40</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Original conditions</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO$_2$ %</td>
<td>9,9</td>
<td>9,8</td>
<td>9,8</td>
</tr>
<tr>
<td>Tflue °C</td>
<td>55</td>
<td>47</td>
<td>41</td>
</tr>
<tr>
<td>Flue gas loss (%)</td>
<td>1,21</td>
<td>0,88</td>
<td>0,64</td>
</tr>
<tr>
<td><strong>Variation of CO$_2$ of 1,5 %</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO$_2$ %</td>
<td>8,4</td>
<td>8,3</td>
<td>8,3</td>
</tr>
<tr>
<td>Tflue °C</td>
<td>55</td>
<td>47</td>
<td>41</td>
</tr>
<tr>
<td>Flue gas loss (%)</td>
<td>1,42</td>
<td>1,04</td>
<td>0,75</td>
</tr>
</tbody>
</table>

As seen in the above table, even 1.5% variation will not impact flue gas losses very much, and differences are below the range of the uncertainty in the determination of the annual efficiency.

An old, traditional, open flue boiler [Q6-K21] from the previous result table

In the case of older boilers, a CO$_2$ difference will impact the efficiency much more, mostly because of much higher flue gas temperatures

<table>
<thead>
<tr>
<th>Nominal Conditions</th>
<th>60/80</th>
<th>40/60</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Original conditions</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO$_2$ %</td>
<td>5,7</td>
<td>5,6</td>
</tr>
<tr>
<td>Tflue °C</td>
<td>130</td>
<td>122</td>
</tr>
<tr>
<td>Flue gas loss (%)</td>
<td>7,91</td>
<td>7,54</td>
</tr>
<tr>
<td><strong>Variation of CO$_2$ of 1,5 %</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO$_2$ %</td>
<td>4,2</td>
<td>4,1</td>
</tr>
<tr>
<td>Tflue °C</td>
<td>130</td>
<td>122</td>
</tr>
<tr>
<td>Flue gas loss (%)</td>
<td>10,39</td>
<td>9,81</td>
</tr>
</tbody>
</table>

4.2.5 Conclusion

We have compared the CO$_2$ or O$_2$ values from the service report with corresponding DGC laboratory tests.

The results demonstrated that CO$_2$ values in the service reports are typically very close to the value measured in the laboratory. This means that we can
conclude that installers are following the rules and instructions, and that there are no additional flue gas losses due to a poor installation or poor service. Moreover, the difference seen for some boilers will only have a very small impact on the boiler efficiency of premix condensing boilers.
5 Other aspects

5.1 Reliability of gas boilers. Lifetime of boilers.

There is not much literature available on the topic of reliability of gas boilers and specifically condensing boilers.

The lifetime of older boilers is, of course, easy to assess when having statistics on boiler failures. This was done in the past, and data from the Danish gas distribution company HMN Naturgas have shown in the past (in the 2000s) that lifetime of gas boilers (traditional) is between 17 and 22 years depending on the boiler model.

The lifetime of boilers as discussed here is defined as the time after installation where 50% of the installed population is not operational anymore.

Recently, the Technology Catalogue /2/ has assumed a lifetime of 20 years in line with other all space heating technologies. However, the value is not based on any investigations.

One important question is to know if condensing boilers will have lifetime similar to traditional boilers. As a matter of fact, condensing boilers and boilers in general have technologies that are more sophisticated (controls, electronic) and thus may increase the frequency of failure, but on the other hand, their construction may be more robust (stainless steel heat exchangers, etc.).

The Building Research Establishment (BRE), which is the UK's major research body for the building industry, has produced guidance on domestic condensing boilers. This was originally published in 2003 as the General Information Leaflet 74 (GIL74), entitled "Domestic Condensing Boilers: the benefits and the myths" /1/. The publication is based on BRE's experience with installed condensing boilers since the 1980s. The BRE says “modern condensing boilers are just as reliable as standard boilers”.

More recent (2015) statistics by HMN /27/ confirm BRE's early statement from 2003 and conclude that condensing boilers' lifetime is not different from that of traditional boilers. The average lifetime from HMN statistic is 18.5 years. The replacing rate is about 5.5%.
Together with HMN, DGC has investigated the feasibility of a method to predict the lifetime of boilers with statistics available on boiler installations. The idea is to observe the evolution of boiler failure statistics and then extrapolate it /16/.

From data available we have demonstrated that a Gaussian distribution model for boiler failures would work for a number of boilers. This would allow foreseeing the average lifetime of boilers when e.g. about 10% of the failure rate is reached.

At present, we have not carried out extended lifetime calculations for many boilers, but extended data for 3 boilers shows lifetimes in the range of 17.5-21 years confirming the assumptions and results presented.

<table>
<thead>
<tr>
<th>Boiler</th>
<th>Lifetime (year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boiler1</td>
<td>17.5</td>
</tr>
<tr>
<td>Boiler2</td>
<td>21</td>
</tr>
<tr>
<td>Boiler3</td>
<td>21</td>
</tr>
</tbody>
</table>
5.2 Legal and regulatory aspects

Gas boilers are subject to EU legislation in order to be granted the CE mark. The main regulations that need to be observed are:

- The Gas Appliances Directive that covers all safety aspects
- The Ecodesign Directive /7/ that impose minimum performances of the appliances (efficiency, emissions, etc.)
- The EU Labelling Directive /8/ that imposes a label so as to allow the user to compare heating appliances

5.3 Servicing of gas boilers in Denmark

All “non-closed combustion” gas appliances and, thus, boilers are subject to a contractual service/maintenance. Moreover, many gas customers also choose to have a maintenance contract for their boiler, also in the case there is no legal obligation.

Each maintenance visit will result in a report. The service report includes information about the boiler condition and operation at the service visit, including a number of measured combustion parameters and information about the installation.

The combustion parameters controlled via measurement are:

- Flue gas temperature
- CO₂/O₂ (%) in the flue gas
- CO (ppm) in the flue gas
- Air temperature

**Flue gas efficiency** can be measured via measurements of flue gas temperature and CO₂ and O₂ when the fuel composition is known. The “on-site full-load operation” is achieved by activating a "chimney sweep function" which in a short period forces the boiler to full-load operation, even though there is not currently a heating demand.

5.4 Cost aspects

The cost of gas boilers is very different depending on the countries /9/, but the most recent data in relation to the Danish Energy Agency's Technology
Catalogue /2/ has shown that the cost of gas boilers and installations has been decreasing in Denmark in the recent years.
Furthermore, various other costs (maintenance, service etc.) are also detailed in the report. Costs aspects have also been investigated in detail in other studies comparing natural gas boilers with other heating technologies /26/.
6 Important aspects to consider when comparing data of gas boilers from this report with other technologies

6.1 General

The document /2/ Technology Data for Energy Plants Individual Heating Plants and Energy Transport, Danish Energy Agency, October 2013 is today a reference document to compare heating technologies. Data from the document have been elaborated and agreed upon by experts and reflects today's state of the art. Calculations comparing heating technologies should as far as possible be based on those data.

6.2 System boundaries

Various aspects of the system boundaries are discussed in the sections 2.2.2, 3.6 and 4.2.1. When comparing annual efficiency with other technologies it is not only important to use an equivalent method and reliable data, but also to use equivalent system boundaries.

Annual efficiencies obtained with the method used in this report are considering among other conditions such as:
- The pump is not part of the boiler system boundaries.
- The heater (boiler) is installed in an unheated room, and case losses are really lost and not participating in the heating of the house.

6.3 Water temperature in distribution systems. Discussion point

In 3.8 we have defined
- \( TT = \text{Traditional temperature here designed with high water temperature in the radiators 60-80 °C} \)
- \( LT = \text{Low temperature here designed with } T_{\text{water average}} = 55 °C \)
- \( MX = \text{Mixed as installation with a mixture of both of the above (old radiator system with floor heating). In this case an equal share of } LT \text{ & } TT \text{ is assumed.} \)

The above was defined in the early 90s when making the first calculations of boiler annual efficiency. One could argue that Low Temperature
installations are nowadays much lower than Twater average = 55 °C used for the definition in the 90s.

In order not to cause confusion in the report we have not changed the definitions, but for future work we should consider the following categories of distribution systems defined according to the temperature:

1) Design temperature: 60-80 °C
2) Design temperature: Twater average = 55 °C (BR 2005)
3) Design temperature: Twater average = 35 °C

The typical distribution systems will mainly depend on type of emitters (radiator or floor heating), the building construction year and possible renovation:

1) *Design temperature: 60-80 °C*
   - Mostly for buildings built before 2005

2) *Design temperature: Twater average = 55 °C (BR 2005)*
   - Buildings built before 2005 designed for condensing boilers
   - Buildings built after 2005
   - Renovated buildings before 2005

3) *Design temperature: Twater average = 35 °C*
   - Floor heating systems
   - Renovated building built after 2005

We do not have data/statistics that can confirm the distribution above, but we are considering to make further investigation on this topic.
7 References


15. BOILSIM A Supporting Tool For Helping The Set Up Of Guarantee Of Results (For Boiler Energy Efficiency. Contract XVII/4.1031/Z/99-309

17. Vurdering af gaskedlers virkningsgrader i almindelige husinstallationer på baggrund af service rapporter og DGC’s testrapporter.

18. Evaluation of the NO\textsubscript{x} emissions of the Danish population of gas boilers below 120 kW. DGC/TCG 2014, Jean Schweitzer, Per G. Kristensen.


21. ADENE, BRECSU (Building Research Establishment Garston, UK).


24. Kedeleffektivitet for oliefyr og naturgaskedler I enfamiliehus, Simon Furbo, Louise Jivan Shah, Christian Holm Christiansen, Karsten Vinkler Frederiksen. 2004


27. Gas kedlers naturlige overlevelse. Ole Albæk Pedersen, Mads Thers Christiansen. HMN Naturgas, GASenergi nr. 5, 2015

28. Gulvvarmeanlæg – en introduktion

ANNEX 1: Database extracts

1- Annual el. consumption and efficiencies for standards heat demand

This table is not public.

2- Other parameters

In addition to the calculated parameters above the database comprises a very large number of data specific to the boilers that we cannot publish in such a report for practical reasons.

However, as an example we detail in the following the data available taking one single example (BA05).

a) Efficiency and emissions measurements

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Pmax 60/60°C</th>
<th>Pmax 40/60°C</th>
<th>Pmax 30/50°C</th>
<th>Pmin 60/60°C</th>
<th>30% 30/30°C</th>
<th>Pmin 30/30°C</th>
<th>30% 40/60°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Return temperature (°C)</td>
<td>59.94</td>
<td>60.05</td>
<td>59.12</td>
<td>59.54</td>
<td>59.99</td>
<td>59.83</td>
<td>60.11</td>
</tr>
<tr>
<td>Flow temperature (°C)</td>
<td>79.87</td>
<td>79.87</td>
<td>79.72</td>
<td>79.77</td>
<td>76.33</td>
<td>76.71</td>
<td>76.90</td>
</tr>
<tr>
<td>Net heat input (kW)</td>
<td>26.22</td>
<td>27.02</td>
<td>27.07</td>
<td>5.66</td>
<td>6.20</td>
<td>6.70</td>
<td>6.00</td>
</tr>
<tr>
<td>Heat output (kW)</td>
<td>25.58</td>
<td>27.11</td>
<td>27.98</td>
<td>6.43</td>
<td>6.80</td>
<td>7.40</td>
<td>6.20</td>
</tr>
<tr>
<td>Net efficiency (%)</td>
<td>97.54%</td>
<td>100.35%</td>
<td>103.34%</td>
<td>96.55%</td>
<td>107.60%</td>
<td>107.60%</td>
<td>100.70%</td>
</tr>
<tr>
<td>Efficiency uncertainty (% rel.)</td>
<td>1.55%</td>
<td>1.49%</td>
<td>1.46%</td>
<td>1.78%</td>
<td>1.87%</td>
<td>1.59%</td>
<td>1.48%</td>
</tr>
<tr>
<td>Flue gas temperature (°C)</td>
<td>79.59</td>
<td>79.79</td>
<td>80.59</td>
<td>35.17</td>
<td>30.00</td>
<td>33.00</td>
<td>40.00</td>
</tr>
<tr>
<td>QO (vol-%)</td>
<td>5.11%</td>
<td>5.41%</td>
<td>5.37%</td>
<td>5.37%</td>
<td>5.20%</td>
<td>5.20%</td>
<td>7.80%</td>
</tr>
<tr>
<td>NOx (mg/kWh)</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>NOx uncertainty (% rel.)</td>
<td>0.83%</td>
<td>0.74%</td>
<td>0.75%</td>
<td>0.07%</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>NOx loss (% of heat input)</td>
<td>0.00%</td>
<td>0.00%</td>
<td>0.00%</td>
<td>0.00%</td>
<td>0.00%</td>
<td>0.00%</td>
<td>0.00%</td>
</tr>
<tr>
<td>Condensate flow (l/h)</td>
<td>0.00</td>
<td>1.03</td>
<td>2.02</td>
<td>0.01</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Condensate flow uncertainty (% rel.)</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Ambient temperature (°C)</td>
<td>21.19</td>
<td>21.76</td>
<td>20.49</td>
<td>30.61</td>
<td>20.40</td>
<td>20.20</td>
<td>21.00</td>
</tr>
<tr>
<td>Ambient pressure (mbar)</td>
<td>1007.00</td>
<td>1006.00</td>
<td>1003.00</td>
<td>1001.00</td>
<td>1001.00</td>
<td>998.00</td>
<td>1001.00</td>
</tr>
<tr>
<td>Humidity (g/kg dry air)</td>
<td>4.81</td>
<td>4.34</td>
<td>2.52</td>
<td>2.19</td>
<td>2.30</td>
<td>2.09</td>
<td>2.40</td>
</tr>
<tr>
<td>CO (mg/kWh)</td>
<td>17.37</td>
<td>26.91</td>
<td>24.98</td>
<td>14.00</td>
<td>12.00</td>
<td>12.00</td>
<td>15.00</td>
</tr>
<tr>
<td>CO uncertainty (% rel.)</td>
<td>14.14</td>
<td>14.26</td>
<td>14.56</td>
<td>16.37</td>
<td>16.50</td>
<td>16.00</td>
<td>15.00</td>
</tr>
</tbody>
</table>

b) Standby losses and measurements on components during the testing

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standby loss (NF) ∆T = 50°C (W)</td>
<td>137</td>
</tr>
<tr>
<td>Standby loss (NF, blocked) ∆T = 50°C (W)</td>
<td>137</td>
</tr>
<tr>
<td>Minimum boiler temperature (°C)</td>
<td>0</td>
</tr>
<tr>
<td>Pre-purge time (s)</td>
<td>0</td>
</tr>
<tr>
<td>Post-purge time (s)</td>
<td>15</td>
</tr>
<tr>
<td>Pump power during efficiency testing (W)</td>
<td>71</td>
</tr>
<tr>
<td>Time constant, heating (s)</td>
<td></td>
</tr>
<tr>
<td>Time constant, cooling (s)</td>
<td></td>
</tr>
<tr>
<td>Pilot flame net heat input (W)</td>
<td>0</td>
</tr>
<tr>
<td>Pilot flame net efficiency (%)</td>
<td>0</td>
</tr>
</tbody>
</table>
c) Hot water production

<table>
<thead>
<tr>
<th>Hot water production</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>(DK test method)</td>
<td></td>
</tr>
<tr>
<td><strong>Standby before tapping</strong></td>
<td></td>
</tr>
<tr>
<td>Heat input (kWh)</td>
<td>5,21</td>
</tr>
<tr>
<td>Ambient temperature (°C)</td>
<td>19,7</td>
</tr>
<tr>
<td>Test duration (h)</td>
<td>71,5</td>
</tr>
<tr>
<td><strong>Tapping</strong></td>
<td></td>
</tr>
<tr>
<td>Heat input (kWh)</td>
<td>11,7</td>
</tr>
<tr>
<td>Heat output (kWh)</td>
<td>12,8</td>
</tr>
<tr>
<td>Maximum water temperature during first tapping (°C)</td>
<td>63,1</td>
</tr>
<tr>
<td>Ambient temperature (°C)</td>
<td>19,9</td>
</tr>
<tr>
<td>Test duration (h)</td>
<td>2,8</td>
</tr>
<tr>
<td><strong>Standby after tapping</strong></td>
<td></td>
</tr>
<tr>
<td>Heat input (kWh)</td>
<td>5,15</td>
</tr>
<tr>
<td>Ambient temperature (°C)</td>
<td>19,8</td>
</tr>
<tr>
<td>Test duration (h)</td>
<td>45,2</td>
</tr>
</tbody>
</table>

d) Electricity consumption

| Total electricity consumption, Pmax heating (W) | 123 |
| Flow at Pmax (l/h)                             |    |
| Total electricity consumption, Pmin heating (W) | 43 |
| Flow at Pmin heating (l/h)                     |    |
| Total electricity consumption, after run time (W) | 26 |
| Flow at after run time (l/h)                   |    |
| Total electricity consumption, Pmax hot water (W) | 123 |
| Electricity consumption, pump after-run hot water (W) | 26 |
| Standby electricity consumption (W)            | 6  |
| Burner fan max/min (W)                        | 67 |
e) Other information
Mainly the boiler data

- Name
- CE number
- Condensing or not
- Type of hot water production (instantaneous or storage)
- Burner type
- Physical size
- Etc.
ANNEX 2: BOILSIM

(Copy of an article published)

BOILSIM (BOILER SIMULATION): A way of calculating annual efficiency for domestic boilers

1. INTRODUCTION

A lot of efforts have being done in the EC in order to reduce carbon emissions and to increase the efficiency for domestic heating in heat equipment like boilers.

For this issue, high efficiency domestic boilers are strongly demanded. One of the main problem found by the EC is the way to calculate the annual efficiency. This calculation is not easy because it depends on many parameters. These parameters can be grouped in two big blocks: the characteristics parameters for the boiler and for the building.

Boilsim (Boiler Simulation) is a method of calculation that have been developed in 1996 in the European project “ANNUAL EFFICIENCY CALCULATION METHOD FOR DOMESTIC BOILERS” under the European SAVE program. Several European organizations joined their effort to set up a European method for calculation of the annual efficiency for domestic boilers: BRITISH GAS, CETIAT, DGC, DTI, GASTEC, GAZ de FRANCE, ITALGAS, LTH, RUHRGAS, TNO ...

This method provides consumers, energy planners, installers, etc... with a tool for selecting the boiler best fitted for the existing or new installation. Boiler manufacturers can also use the method in order to improve the design of their products.

2. PRINCIPLE

The BoilSim model is a complex function that calculates the part load efficiency for a given conditions (heat load, water flow temperature, water flow rate, etc.). Another factor taken into account is the heat demand of the building.

The calculation is done using an energy balance of the boiler and iteration loops. This energy balance is done taken into account real laboratory tests in determinated operating conditions.

BoilSim finds the annual efficiency of boilers under real operating conditions along the year. These monthly operating conditions are determined by the dynamic interaction between building, climate, installation, boiler and user behaviour influence parameters such as:

- The turning on and off of the boiler: Night and day set back
- The continuously changing boiler water temperature
- The changing water flow rate through the boiler
The annual efficiency is calculated by integrating the individual heat demands, based on external temperature distribution over the whole year. This annual efficiency depends on a lot of parameters (see figure 1) such as:

- Climate data
- Annual heat demand
- Boiler parameters
- Pump boiler parameters
- Control system parameters
- Installation parameters

Figure 1: Schematic principle of BoilSim to calculate annual efficiency

### 3. Calculation of Annual Efficiency

The annual efficiency of a boiler in a specific configuration is obtained by combining the part-load efficiencies for a number of operating conditions and their weighting factors. This is done according to the following formula:
\[ \eta = \frac{\sum_{i=1}^{n} \phi_i \cdot Z_i}{\sum_{i=1}^{n} \phi_i \cdot \eta_{p,i}} \]

\( \phi_i \) = boiler heat load for operating condition \( i \)

\( Z_i \) = weight factor for operating condition \( i \)

\( \eta_{p,i} \) = number of operating conditions

When modelling the boiler environment one has to look at those parts of the environment that have an influence on the operating condition of the boiler. Considering this one could assume the following environment parts to affect the boiler operating conditions:

- The building in which the boiler is installed
- The outdoor temperature distribution
- The use behaviour
- The nominal heat output of the boiler installed
- The control system of the boiler and its pump
- The type and design parameters of the heating system connected to the boiler
- The hydraulic adjustment of the installation
- The room where the boiler is installed

4. **MAIN PARAMETERS IN THE MODEL**

A very useful quantity to describe the building is its annual heat demand. The boiler installed is described by its nominal heat output. The outdoor temperature distribution can be described by the degree-days method and the user behaviour can be modelled by its desired room temperature during a day.

4.1. **Annual heat demand**

To determine a boiler heat load representative for a certain period the annual heat demand is weighted with the number of degree-days in that period. The so found “period heat demand” is then divided by the duration of the period and the nominal heat output of the boiler in order to find the boiler heat load. In other words, we take the annual heat demand and we distribute it by periods taken into account the degree-days and then we calculate an average boiler heat load for that period.

4.1.1. **The degree-day method**

The annual heat demand of a building gives the total heat which has to be supplied by the heating installation and the boiler over an entire year. This total amount consists of
several parts corresponding to the heat demand in a certain period in the year. This "period" heat demand is mainly dependent on the temperature difference between inside and outside. In the winter the "period" heat demand will be high, at the beginning and the end of the heating season the "period" heat demand will be low. A high heat demand will cause a high relative boiler load, whereas a low heat demand will cause low relative boiler load.

In order to be able to calculate the actual heat demand in a certain period we make use of a degree-day method. The degree-day method calculates the heat demand in a certain period by multiplying the annual heat demand by the fraction of degree-days in that period.

\[
Q_i = \frac{DGi}{TDG} \cdot Q_a
\]

\(DGi = \) Number of degree-days in interval \(i\)

\(TDG = \) Total number of degree-days

\(Q_a = \) Annual heat demand of the building (J)

\(Q_i = \) heat demand in interval \(i\) (J)

The definition of degree-days is as follows:

\[
DG_i = D_i \cdot (T_{in,i} - T_{out,i})
\]

\(D_i = \) number of heating days in interval \(i\)

\(T_{in,i} = \) indoor temperature in interval \(i\) (°C)

\(T_{out,i} = \) outdoor temperature in interval \(i\) (°C)

4.2. Boiler type characteristics

In BoilSim the model distinguishes between condensing and non-condensing boilers and between fan-assisted and atmospherics burners. In the BoilSim terminology the definition of a fan-assisted boiler is simply all boilers equipped with fan.

Selection of the burner control is straight forward. Though, modulating boiler means a boiler where the control of the fan is infinitely variable. Among the newest advanced boilers, designs with infinitely variable control of the pump are also seen. The model is not dealing with the influence which this matter could have on efficiency.

The modulating strategy is related to how the boiler is operating in case the heat input is less than the minimum nominal heat input (determined from test). The strategy is either than the boiler is operating with minimum nominal heat input or with maximum nominal heat input. The latter is in the Boilsim terminology called 'Other Strategies'.
5. **CONCLUSIONS**

This methodology that is being implemented in the European project BISON ([www.boilerinfo.eu](http://www.boilerinfo.eu)) will have a very big impact in the boiler market and will promote high efficiency boilers.

The method has been implemented in a easy-to-use computer program which provides consumers, installers, energy consultants etc with a tool for selecting the boiler best fitted for the existing installation.

Boiler manufacturers could use the method in order to improve the design of their products.

This method will bring attention to the energy efficiency of the entire system: boiler, building, heat distribution system and components.

Due to the number of boilers installed in the EC every year, the economic impact of the method could be very substantial.

6. **REFERENCES**


ANNEX 3: Low (net) and high (gross) calorific value ratio

For **pure methane** the ratio $H_s/H_i$ is **1,110**

The ratio changes depending on the gas composition.


- With the composition of **Danish natural gas (e.g. in 1993)** $H_s/H_i$ is slightly lower: **1,106**
ANNEX 4: Graph for annual efficiency of boilers, period 2010-2015
(same as in the report, but larger for user convenience)