Raising the efficiency of boiler installations (BOILeff)

Guenter R. Simader
Austrian Energy Agency
Austria
guenter.simader@energyagency.at

Georg Trnka
Austrian Energy Agency
Austria

Claus Barthel
Wuppertal Institut
Germany

Gerhard Wohlauf
Wuppertal Institut
Germany

Ferenc Lezsovits
Innoterm Energetics Ltd.
Hungary

Alberto Coronas
URV – Crever
Spain

Joan Carles Bruno
URV – Crever
Spain

Maria Puig-Arnavat
URV – Crever
Spain

Núria Quince
URV – Crever
Spain

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Abstract
Installed boilers do not operate as efficiently as they could. While test cases demonstrate that boilers could achieve high efficiencies, their real performance is much lower. This observation could be verified by the German research Project "Optimus" which deals with the optimization of installed heating systems and by an implemented field test in Germany to evaluate the operation of gas fuelled condensing boilers.

Starting from this analysis that many boiler installations suffer from serious shortcomings, BOILeff project was initiated to develop and to assess two new market approaches for improving the efficiency of boiler installations.

The first market approach is a high quality declaration. It is based on a checklist of quality criteria for boiler installations, which should form a part of the contract between installers and end consumers. The second approach is a performance declaration. The installer should be able to pledge a certain annual efficiency of the boiler by his high quality installation.

By a field test including around 50 installations, the practicability and effectiveness of both new approaches are evaluated during the heating period 2008/2009.

Furthermore BOILeff activities should contribute to a new voluntary measure under discussion to increase the energy efficiency in heating systems and build-up on article 8 (inspection of boilers and heating systems) of EPBD and relate on the Ecodesign Directive.

Introduction
Space heating is the largest component of energy consumption in households in virtually all Member States, accounting for 67% at the level of the EU-15, followed by water heating and appliances (EEA 2008).

Demonstrations based on laboratory analysis show that new condensing boilers achieve efficiencies of over 100%, both for gas and oil boilers. This is in strong contrast with selective results from field studies in real conditions, where the annual energy use efficiencies of boilers were up to 15 to 20 % lower than under optimal conditions in demonstration cases (Wolff 2004, Erb 2004).

While new condensing boilers have already reached a stage of technological optimum, the installations of heating systems still offer broad opportunities for efficiency improvements.

Starting from the observation that there exist serious shortcomings in common heating system installations, the project BOILeff consisting of the project partners Austrian Energy Agency, Wuppertal Institute, Innoterm, the Regulatory Authority for Energy (RAE), and the University of Rovira i Virgili pursue the goal of improving the quality of boiler installations through developing and testing of two new market approaches.

Typical weaknesses of boiler installations
In the first phase of BOIleff project 75 audits of typical residential buildings with a nominal power range of around 20 kW[1] have been carried out in Austria, Germany, Hungary, Spain, and Greece to document the major weaknesses of boiler instal-

1. The project targets typical residential buildings with a nominal heat load of around 20 kW.

lations in the different countries. The following typical installation weaknesses were observed:

- Incorrect boiler sizing (no heat load calculation performed) (66% of investigated systems)
- Too high exhaust gas losses, surface losses and/or ventilation losses (72%)
- Insufficient isolation of armatures and pipes (93%)
- Missing control systems (thermostatic valves, etc.) (57%)
- No hydraulic balance performed (95%)
- etc.

In total 27 major weaknesses were identified, summarised, published in form of a list and communicated to the relevant stakeholder groups (installers, end-consumers, etc.) in order to raise awareness concerning energy efficient heating systems in new installations. A summary of results both of performed audits and typical weaknesses are available in (Barthel 2008) and (Simader 2008).

Furthermore these results were the basis for developing two new market approaches:

- a declaration of high quality installation (DHQUI), and
- a performance declaration.

The first approach is a high quality declaration and contains a set of quality criteria for a high quality installation of the heating system. This declaration should become part of the contract between installer and end-consumer when selling new installations. The second one – called performance declaration – includes a guarantee of the installer to achieve a certain "high" seasonal efficiency of the heating system. This second information to the end consumer justifies the costs – a high quality installation costs normally more than a cheap "standard" one – and indicates the expected seasonal efficiency and (!) the energy savings of the new heating system. These new services are needed to raise the awareness of the end user in order to differ between high and low quality heating installations and to support the installer to sell more expensive but higher quality installations. Both services get tested and evaluated by field tests involving around 60 heating systems in the heating period 2008/2009.

Declaration of High Quality Installation and Guaranteed Performance

The typical business case of BOILeff installations (residential buildings with a nominal heat load of around 20 kW) includes the modernisation of old heating systems. When the heating system breaks down and the building owner receives the information from the installer that a repair service is more expensive than a new heating system the developed BOILeff services should take place.

An end-consumer can normally only judge the investment costs for his future heating system. He is normally **not in the position** to evaluate from the quotation whether the new heating system will perform in an energy efficient way because he receives in the quotation only information about components, materials and a summary of working hours (in the best case) necessary to install the new heating system or to make changes in the old system.

For this reason, the end-consumer can evaluate the quotation only according to the price, not to the quality. Consequently quality orientated installers have difficulties to establish such business models. In order to address this issue, a set of quality criteria was developed to assure the installation of an energy efficient heating system.

The declaration of high quality installation includes the following major criteria:

- Implementation of a heat load calculation
- Installation of a high efficient boiler technology (e.g. condensing boilers)
- Calculation of the hydraulic system for dimensioning of the circulation pump
- Installation of the high efficient circulating pump(s)
- Correct dimensioning of the domestic hot water demand and installation of the corresponding storage tank
- Implementation of the hydraulic balance of the heating system
- Implementation of pipe– and armature insulation

A detailed discussion showing and (!) explaining the different criteria would be beyond the scope of this paper; the documentation is available in (Barthel 2008).

The different criteria and the implementation possibilities of this declaration by installers and other stakeholder groups got discussed in several meetings in the different countries involving also their perspectives in developing this new service and resulting in up-dated and country-specific versions of the declaration.

As already pointed out high-quality installation will be more expensive than cheap standard installations. For this reason the installer has to provide the end-consumer additional information justifying the higher costs by showing the energy savings in the long run.

By the performance declaration the installer guarantees the costumer a high annual performance of his new heating system. For the calculation of the average annual performance and the energy savings of the old and the new high quality heating system, the Austrian Energy Agency developed a calculation tool taking into account typical business situations of installers. The calculation method of this tool was developed by the German university of applied science in Wolfenbüttel and is called "finger print method" taking into account the following input parameters:

- Calculated heat load of the building
- Typical outdoor temperature
- Defined indoor temperature
- Building insulation standard
- Insulation of the pipes
- Temperature spread of the system
- Dimension of the domestic hot water storage tank

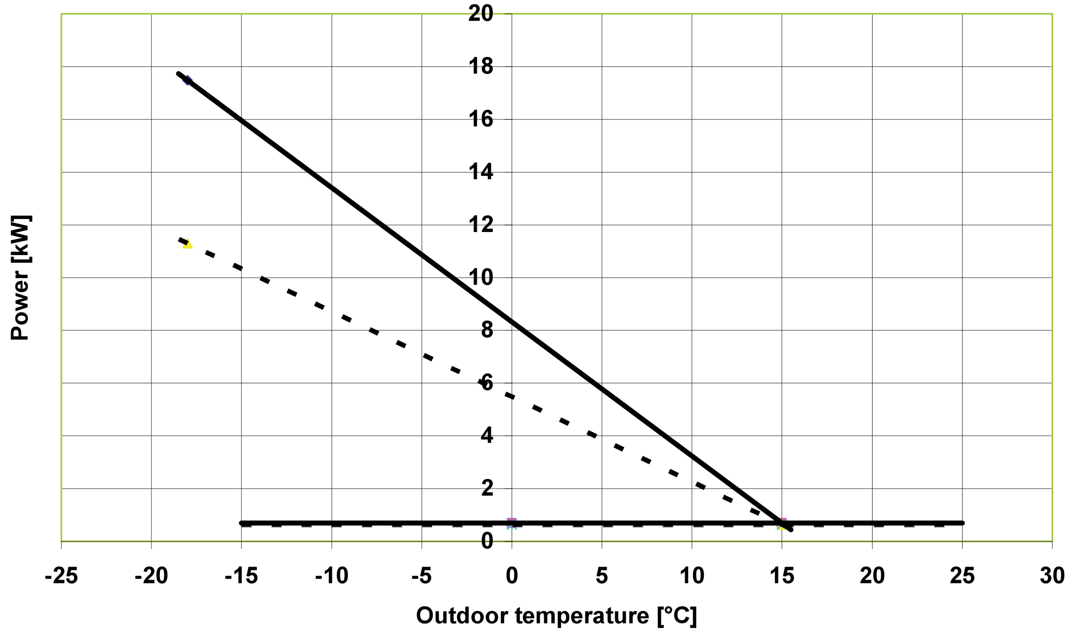

Figure 1. "Finger prints" for a typical single family house with a heat load of 10 kW equipped with an old boiler [30 kW / η 76% (Hi)] continuous lines and a new condensing boiler [11,5 kW / η 95% (Hi)] dashed lines. (Source: Austrian Energy Agency)

- Performance data of the boiler
- Number of inhabitants
- Number of bathtubs, showers, etc.
- Average outdoor temperature in the heating period
- Average days of the heating period

Because this additional information to the end-consumer is crucial for implementing high quality installations on the market (due to the higher costs), the performance guarantee is explained more in details in the next chapter.

APPLYING THE "FINGER PRINT METHOD" IN THE PERFORMANCE GUARANTEE

During the first visit(s) at the customer site the installer has to record the required input data for the calculation tool. Subsequently, he performs a heat load calculation of the building. Next steps include the calculation of the average power for the consumption of domestic hot water ($\dot{Q}_{TWW}$) and distribution loses ($\dot{Q}_d$).

Next steps include the identification – normally listed on the specification sheets – of the boiler capacity and the stand-by losses both of the old and the new boiler. After that, the calculation of the mean heating load ($\dot{Q}_{h,m}$) within the heating period has to be performed. From this value the mean boiler capacity ($\dot{Q}_{K,m}$) is derived and in consequence the mean fuel input ($\dot{Q}_{F,m,1}$) within the heating period is derived using the following equations:

$$\dot{Q}_{h,m} = H * (t_{HG} - t_{a,m}) \quad (1)$$

H = Heat load of building $[kW/K]$

t_{HG} = Average temperature level starting heating $[K]$

$t_{a,m}$ = Mean ambient temperature in the heating period $[K]$

$$\dot{Q}_{K,m} = \dot{Q}_h + \dot{Q}_d + \dot{Q}_{TWW} \quad (2)$$

$\dot{Q}_h$ = Heat output $[kW]$

$\dot{Q}_d$ = Losses of distribution system $[kW]$

$\dot{Q}_{TWW}$ = Power for domestic hot water $[kW]$

$$\dot{Q}_{F,m,1} = \left(\frac{1}{\eta_K} - \frac{q_B}{\eta_K} \right) * \dot{Q}_K + \frac{q_B}{\eta_K} * \dot{Q}_{K,N} \quad (3)$$

q_B = Specific standby losses [kW]

η_K = Efficiency of boiler [-]

$\dot{Q}_K$ = Nominal boiler capacity [kW]

$\dot{Q}_{K,N}$ = Nominal output of boiler [kW]

The second step includes the calculation of the mean fuel input ($\dot{Q}_{F,m,2}$) outside the heating period (summer period). The heat input for the domestic hot water production ($\dot{Q}_{TWW}$) and the distribution losses ($\dot{Q}_d$) have to be used as follows:

$$\dot{Q}_{F,m,2} = \left(\frac{1}{\eta_K} - \frac{q_B}{\eta_K} \right) * (\dot{Q}_K + \dot{Q}_{TWW}) + \frac{q_B}{\eta_K} * \dot{Q}_{K,N} \quad (4)$$

As a result of the calculations the "finger prints" of the old and the new heating systems is ploted. *Figure 1* shows both the dependency of the combustion power from the outdoor temperature and the sockets for the domestic hot water.

The calculation of the seasonal efficiency of the boiler (respectively heating system) (η_a) is based on the operational hours in the heating period (winter season) (h_{HP}) and in the summer season (h_{SZ}) (following equations (5) and (6). The operational hours are linked to the site-specific climate situation using statistical climate data sets (normally available by the central offices for meteorology and climatology).

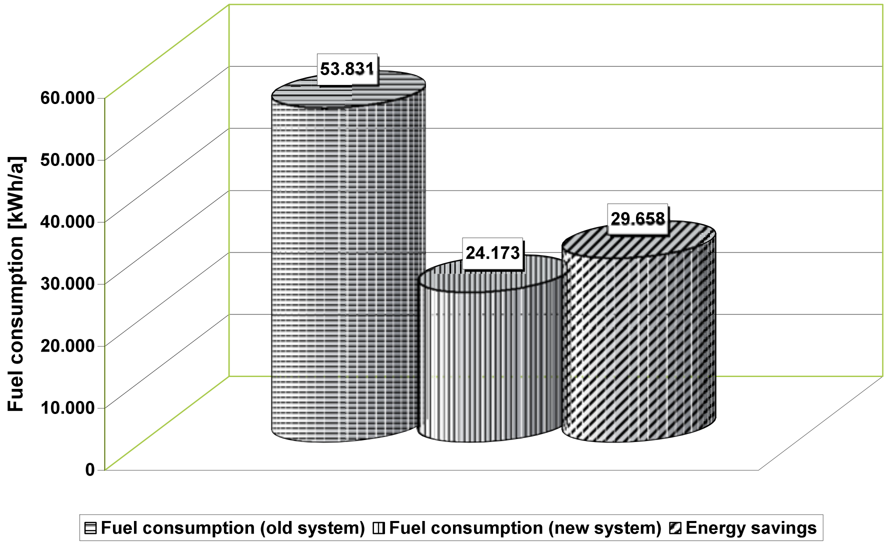

Figure 2: Energy savings based on "finger print" method using an Austrian refurbishment case with an old heating system from the 70s (boiler systems are the same than in Figure 1), for further details concerning data sets see (Simader 2009). (Source: Austrian Energy Agency)

$$Q_F = \dot{Q}_{F,m,1} * h_{HP} + \dot{Q}_{F,m,2} * h_{SZ} \quad (5)$$

$\dot{Q}_{F,m,1}$ = mean fuel input in the heating season [kW]

h_{HP} = operational hours in the heating period [h]

$\dot{Q}_{F,m,1}$ = Nominal output of the boiler [kW]

h_{SZ} = mean fuel input in the heating season [h]

$$\eta_a = \frac{\left(\dot{Q}_K * h_{HP} + \left(\dot{Q}_d + \dot{Q}_{TWW}\right) * h_{SZ}\right)}{Q_F} \quad (6)$$

Q_F = Fuel input [kWh]

Other parameters already defined in equations (2), (4), (5).

Finally, the fuel consumption based on the average annual energy consumption (Q_F) by using the higher heating value (HHV) of the used energy carrier can be calculated.

After comparing the seasonal efficiencies of the old and the new boiler system a comparison between the efficiencies of both boilers (respective heating systems) including the fuel consumption will be performed. Consequently, the end-consumer receives information concerning the efficiencies and future energy (and cost) savings. An example showing high efficiency savings in a typical Austrian refurbishment case with an old heating system from the 1970s is shown in *Figure 2*.

Field test

Presently, the high quality declaration and the performance declaration are tested and evaluated by field tests. The field tests include around 50 installations in Austria, Germany, Hungary, Spain, and Greece and are carried out in the current heating season 2008/2009. The field tests run till the end of May 2009. For this reason the final results of the field tests will be made available in June 2009. At this stage, first results of the Austrian cases are shown below.

For the field tests, every heating system was equipped with additional test equipment as follows[2]: oil meter[3], heat meter placed in heating circuit, heat meter placed in domestic hot water circuit, additional heat meters if necessary (f. ex. in case of an additional heating circuit).

The new heating systems were installed following the quality criteria of the "declaration of high quality installations". On basis of the readings, the seasonal efficiency and the guaranteed energy savings of the new heating systems (in comparison with the old heating systems) get evaluated[4]. By the separate metering of the heating circuit and the domestic hot water circuit, it can be clearly differed between the efficiency of the system in the heating period and in the summer period. Up to now, preliminary results are available from 10 Austrian ongoing field tests (see figure 3[5]).

The first evaluations of the Austrian field tests show a performance of gas condensing systems between 88,2% and 97,1% (HHV). The performance of the oil condensing systems varies between 84,8% and 90,9% (HHV). The pellets boiler shows an average performance of 90,7% (LHV) and the firewood fuelled boiler shows an average performance of 85,9% (LHV).

Compared to seasonal efficiencies of standard systems, the first metering results of BOILeff installations show excellent performance[6]. The BOILeff gas fuelled systems show presently

2. The principal measurement concepts were discussed in detail prior to the installation of the meters and published in (Lezsovits 2008).

3. Gas metering includes the standard gas meters of the gas utility companies.

4. In case of new buildings and of new heating systems (with no possibility to compare it to old existing heating systems) a typical standard quotation (low temperature boiler, insufficient insulation of pipes, etc.) can be taken into account for exemplary reasons by the installer.

5. Regarding the progress of monthly use efficiencies: The calculated use efficiencies of gas and oil fuelled systems are based on the higher heating value (HHV). The calculated use efficiencies of biomass fuelled boilers is based on the lower heating value (LHV) because the condensing technology has not been deployed successfully in biomass boiler systems up to now.

6. Taking into account the operation in the summer period, it is expected that the efficiencies will slightly decline.

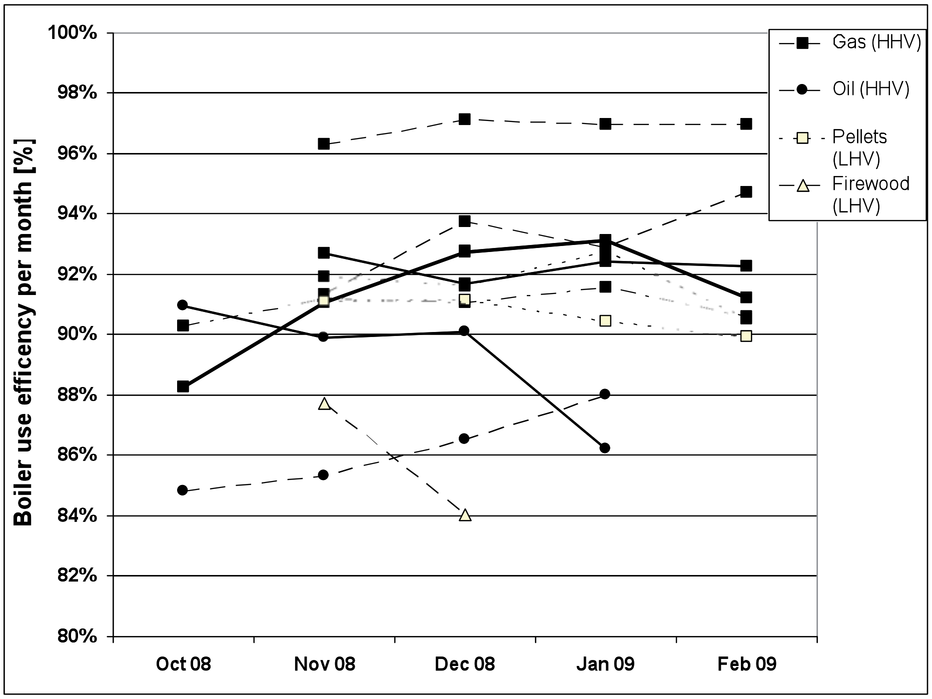

Figure 3: Progress of the monthly use efficiencies of 10 Austrian BOILeff installations including six gas condensing systems (lines including black squares), two oil condensing systems (lines including black bullets), one pellets system (dashed line with white squares), one firewood system (line including white triangles) (Simader 2009). (Source: Austrian Energy Agency)

an improvement of 20,6% compared to standard systems, oil systems of 12,7%, the pellets system of 16,7%, and the firewood system of 13,9%[7]. Already at this stage, it is expected that these preliminary results will be confirmed by the final evaluation in June 2009 (including the test results of the project partners Germany, Hungary, Spain and Greece).

Conclusion

The objective of the European project BOILeff is to improve the quality of boiler installations by developing of two new services for the heating industry: a declaration of high quality installation (DHQUI), and a performance declaration.

The high quality declaration contains a set of quality criteria for a high quality installation of the heating system. This declaration should become part of an offer from installers when selling new installations. The second one – the performance declaration – includes a guarantee of the installer to achieve a "high" seasonal efficiency and significant energy savings of the new heating system. This second information to the end consumer justifies the higher investment costs; normally a high quality installation will cost more than a cheap "standard" one.

These new services are needed to raise the awareness of the end-user in order to differ between high and low quality heating installations, creating WIN/WIN/WIN situations for the installers by higher turnover rates, for end-consumers by lower energy consumptions in the long run and to the society by increasing the security of supply and by decreasing the import dependency from fossil fuels.

In the present heating period (2008/2009), both services are tested and evaluated by 50 field tests in Austria, Germany, Hungary, Spain, and Greece. Up to now, preliminary results are available from 10 Austrian cases showing excellent performance. Compared to seasonal efficiencies of standard systems BOILeff installations show improvements between 12,7% and 20,6% depending on the fuel used. It is expected that these preliminary results will be confirmed by the final evaluation in June 2009.

Furthermore, the implementation of the declaration of high quality installations is also foreseen in some countries like Austria when launching future boiler exchange programs as additional subsidy criteria.[8] Moreover, these new services and quality criteria should build-up on the activities presently under way concerning the implementation of article 8 (…the inspection of hot water boilers used for heating of buildings) of EPBD directive[9] and contribute in the discussion when implementing the ecodesign directive (Energy using Products – 2005/32/EC) (LOT 1 – Boilers and LOT 2 – Water Heaters).

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[R 2] D. Wolff, et. al., "Felduntersuchung: Betriebsverhalten von Heizungsanlagen mit Gas-Brennwertkesseln", Wolfenbüttel, April 2004

7. Annual efficiencies of standard installations in Austria are: gas – 76 % (HHV); oil – 75 % (HHV), pellets – 74 % (LHV), firewood – 72 % (LHV) (Zach 2008).

8. Investment programs for changing old boilers against new boilers. So far only the boiler was considered in such programmes, but not the overall heating system.

9. EPBD is the abbreviation for "Energy Performance Buildings directive".

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