

# **Raising the Efficiency of Boiler Installations (BOILeff)**

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## **Abstract**

Insufficient installations of heating systems lead to low seasonal efficiencies of new boilers. Test cases demonstrate that new boilers could achieve high efficiencies but unfortunately 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, the 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. This declaration is included in the contract between installers and end consumers. It provides a checklist of quality criteria for a high quality installation. The second approach is a performance guarantee. The installer should be able to pledge a certain seasonal efficiency of the boiler by his high quality installation. A field test of about 50 installations is evaluating the practicality and effectiveness of both new approaches during the heating period 2008/2009. The BOILeff activities could 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 to 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). [1]

Demonstrations based on laboratory analysis show that new condensing boilers achieve efficiencies of over 100 %<sup>1</sup>, both for gas and oil boilers. This contrasts with selective results from field studies in real conditions, where the seasonal efficiencies of boilers were up to 15 to 20 % lower than under optimal conditions in demonstration cases. [2][3] While new condensing boilers are already high efficient with little room for improvement, 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 aims to improve the quality of boiler installations by developing and testing of two new market approaches.

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<sup>1</sup> Based on the lower heating level (LHV)

## Typical weaknesses of boiler installations

In the first phase of the project 75 audits of typical residential buildings with a nominal power range of about 20 kW have been carried out in Austria, Germany, Hungary, Spain, and Greece to document the major weaknesses of boiler installations in the different countries. The following installation weaknesses were revealed:

- 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 insulation of armatures and pipes (93 %)
- Missing control systems (thermostatic valves, etc.) (57 %)
- No hydraulic balance performed (95 %)

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 [4] and [5].

These results were also the basis for developing of two new market approaches:

- The first approach is a declaration of high quality installation (DHQUI), and
- the second one is a performance guarantee (GPQU).

The declaration contains a set of quality criteria for a high quality installation. This declaration should become part of the quotation of the installer to the end-consumer. 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 “extra” costs – a high quality installation usually costs more than a cheap “standard” one – and indicates the expected seasonal efficiency and(!) the expected future energy savings of the new heating system.

These new services are needed to raise the awareness of the end-consumer 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 about 50 heating systems in the heating period 2008/2009.<sup>2</sup>

## Declaration of High Quality Installation (DHQUI) and Guaranteed Performance Quality (GPQU)

The typical business case of BOILeff installations (residential buildings with a nominal heat load of about 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 very expensive and doesn't pay off any more, then the developed BOILeff services should take place.

An end-consumer can usually only judge the investment costs for his future heating system. He is not in the position to evaluate the quotation whether the new heating system will perform in an energy efficient way or not. The end-consumer 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, installers have difficulties to establish quality-orientated business models. In order to address this issue, a set of quality criteria was developed to assure installations in an energy efficient way.

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

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<sup>2</sup> In the time when writing this paper the field tests are still ongoing.

- Installation of 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 [6]. The different criteria and the implementation possibilities of this declaration by installers got discussed in several stakeholder meetings in the different countries taking into account their perspectives in developing this new service and resulting in up-dated and country-specific versions of DHQUI.

As already pointed out high-quality installations 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.

With the performance guarantee (GPQU) the installer guarantees the end-consumer a high seasonal efficiency of his new heating system. For the calculation of the seasonal efficiency and the energy savings of the new high-quality system compared to the old heating system, a calculation tool was developed taking into account typical business situations of installers. The calculation method of this tool was developed by the German University of Applied Sciences in Wolfenbüttel and is called “finger print method” using the following input parameters:

- Calculated heat load of the building
- Standard outside temperature
- Indoor temperature
- Building insulation standard
- Insulation of the pipes
- Temperature distribution of the system
- Dimension of the domestic hot water storage tank
- Performance data of the boiler
- Number of tenants
- Number of bathtubs, showers, etc.
- Average outside temperature in the heating period
- The number of 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), more details of the performance guarantee are given in the next chapter.

### **Applying the “finger print method” in the performance guarantee (GPQU)**

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 followed by calculations of the average power for the consumption of domestic hot water ( $\dot{Q}_{TWW}$ ) and distribution losses ( $\dot{Q}_d$ ).

Next steps include the identification – usually 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 heat 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:

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

$H$  = Specific heat load of building [kW / K] Equ. (1)  
 $t_{HG}$  = Average temperature level starting heating [K]  
 $t_{a,m}$  = Mean ambient temperature in the heating period [K]

$$\dot{Q}_{K,m} = \dot{Q}_{h,m} + \dot{Q}_d + \dot{Q}_{TWW}$$

$\dot{Q}_{h,m}$  = Average heat output [kW] Equ. (2)  
 $\dot{Q}_d$  = Losses of distribution system [kW]  
 $\dot{Q}_{TWW}$  = Power for domestic hot water [kW]

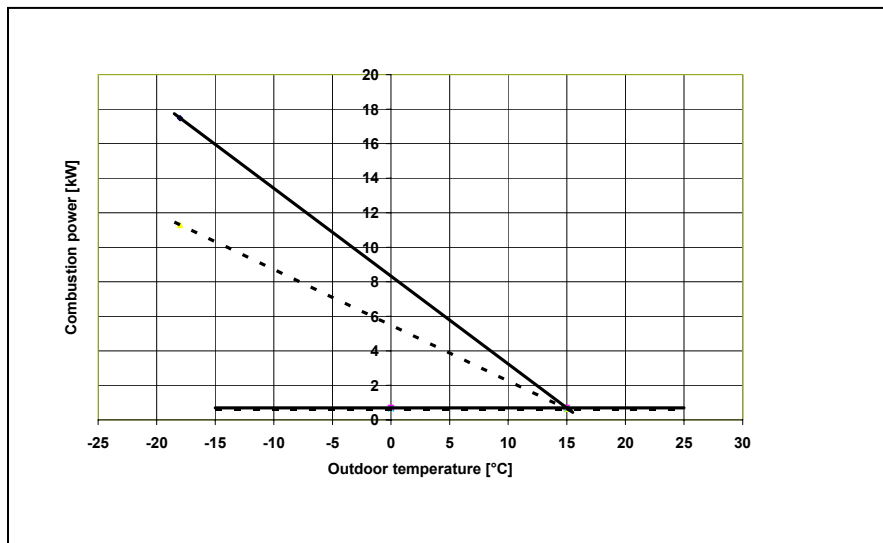
$$\dot{Q}_{F,m,1} = \left( \frac{1}{\eta_K} - \frac{q_B}{\eta_K} \right) * \dot{Q}_{K,m} + \frac{q_B}{\eta_K} * \dot{Q}_{K,N}$$

$q_B$  = Specific standby losses [-] Equ. (3)  
 $\eta_K$  = Efficiency of boiler [-]  
 $\dot{Q}_{K,m}$  = Average 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:

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

As a result of the calculations the “finger prints” of the old and the new heating system are plotted. Figure 1 shows both the dependency of the combustion power on the outside temperature and the socket for the domestic hot water.



**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%] continuous lines and a new condensing boiler [11,5 kW / η=95 %] dashed lines [7]**

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

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

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

$$h_{HP} = \text{operating hours in the heating period [h]}$$

$$\dot{Q}_{F,m,2} = \text{mean fuel input in the summer season [kW]}$$

$$h_{SZ} = \text{operating hours in the summer season [h]}$$

Equ. (5)

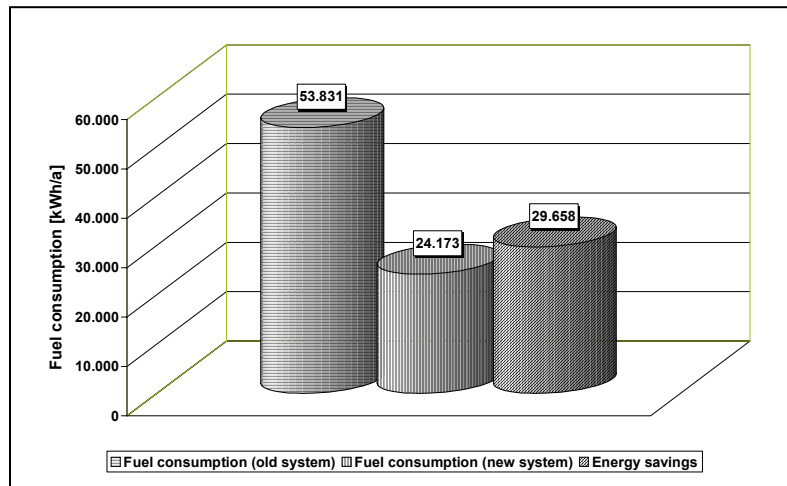
$$\eta_a = \frac{(\dot{Q}_{K,m} * h_{HP} + (\dot{Q}_d + \dot{Q}_{TWW}) * h_{SZ})}{Q_F}$$

$$Q_F = \text{Fuel input [kWh]}$$

Equ. (6)

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

Finally, the fuel consumption based on the average seasonal energy consumption ( $Q_F$ ) by using the higher heat 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.



**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 as in Figure 1) [7] (Source: Austrian Energy Agency)**

## Field tests

Presently, the high quality declaration and the performance guarantee are tested and evaluated by field tests. For the field tests typical residential buildings with a heat load up to 20 kW have been taken into account. The field tests include about 50 installations in Austria, Germany, Hungary, Spain, and Greece, and are carried-out in the current heating season 2008/2009.

For the field tests, every heating system was equipped<sup>3</sup> with additional test equipment as follows<sup>3</sup>: oil meter<sup>4</sup>, heat meter placed in the heating circuit, heat meter placed in the domestic hot water circuit,

<sup>3</sup> The principal measurement concepts were discussed in detail prior to the installation of the meters and published in [9].

<sup>4</sup> Gas metering includes the standard gas meters of the gas utility companies.

and additional heat meters if necessary (e. g. for solar thermal systems or in case of an additional heating circuit). The readings run till May/June 2009. For this reason the final results of the field tests will be made available by July 2009. At this stage, first results of 12<sup>5</sup> Austrian cases are shown below (see Table 1 and Figure 3).

**Table 1 Ongoing field tests in Austria<sup>6</sup> [8]**

Nr.	Type of building	Fuel	Location	Heat load of the building [kW]	Calculated seasonal efficiency by the "finger print method" [η]	Measured seasonal efficiency [η]
1	flat	gas	Vienna	13,1	88,1	88,8
2	flat	gas	Vienna	3,3	85,7	88,4
3	single family house	gas	Herzogenburg (Lower Austria)	5,8	85,1	88,1
4	single family house	gas	Vienna	11,4	92,0	N.A. <sup>7</sup>
5	single family house	gas	Maria Enzersdorf (Lower Austria)	4,65	85,7	85,4
6	single family house	gas and solar	Herzogenburg (Lower Austria)	11,2	89,4	91,3
7	single family house	gas and solar	Linz (Upper Austria)	7,5	89,6	88,2
8	single family house	gas	Pucking (Upper Austria)	12	92,2	89,5
9	single family house	oil	Schwanenstadt (Upper Austria)	8,3	87,1	85,8
10	single family house	oil	Pucking (Upper Austria)	9,8	90,8	83,5
11	single family house	biomass and solar	Klosterneuburg (Lower Austria)	4,15	76,4	73,9
12	single family house	biomass and solar	Seekirchen am Wallersee (Salzburg)	11	88,9	90,9
13	small multi family house	gas and solar	Neupurkersdorf (Lower Austria)	22	93,3	94,9

The first evaluations show a performance of gas condensing systems between 86,2 % and 96,6 % (HHV). The performance of the oil condensing systems varies between 82,3 % and 88,0 % (HHV). The pellets boiler shows an average performance of 90,9 % (LHV) and the firewood fuelled boiler shows an average performance of 73,9 % (LHV). (see Figure 3)

When comparing the achieved seasonal efficiencies with the guaranteed efficiencies based on GPQU the following conclusions can be drawn:

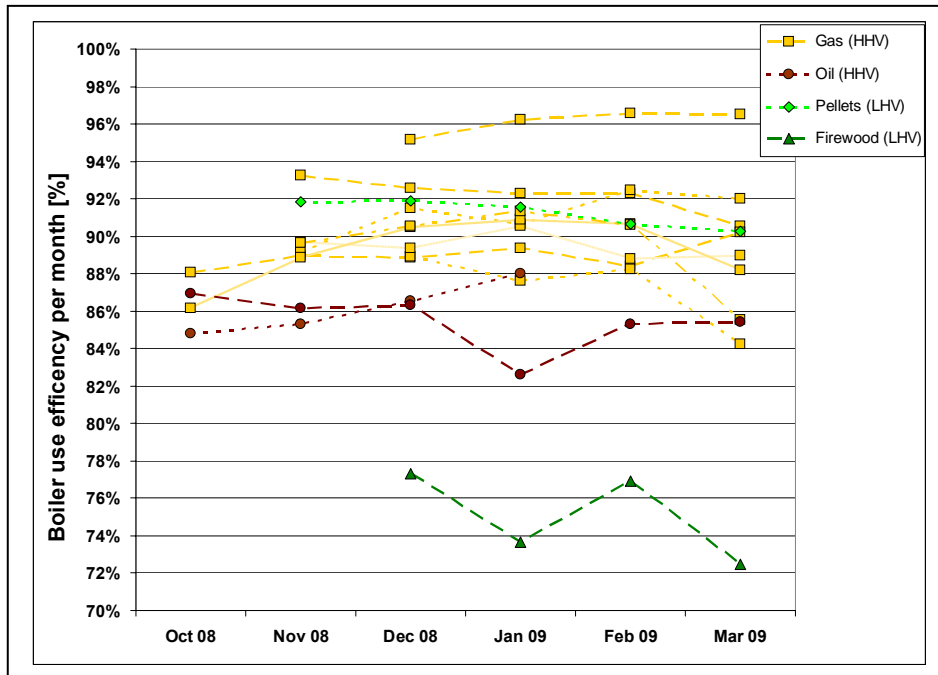
- Seven systems (Five from eight gas systems; two biomass systems) have a higher seasonal efficiency than calculated.
- Three gas systems show a negative deviation (compared to the calculated value) of < 3 %.
- The two oil systems have a negative deviation from the calculated values of 1,3 % and 7.3 %, respectively.

Taking into account technical reasons why one of twelve system shows a deviations > 7 %, it can be concluded that guarantees with a security band of three percentage points can be issued by installers when the installations are based on DHQUI. Already at this stage, it is expected that these preliminary results will be confirmed by the final evaluation in July 2009 (including also the test results of the project partners Germany, Hungary, Spain and Greece).

<sup>5</sup> Unfortunately in one single family house in Vienna the refurbishment of the heating system and the installation of the metering equipment couldn't be finished until March 2009. For this reason only 12 readings are available till now.

<sup>6</sup> The calculated and measured seasonal efficiencies of gas and oil fuelled systems are based on the higher heating value (HHV). The calculated seasonal efficiencies of biomass fuelled boilers are based on the lower heating value (LHV) because the condensing technology has not been deployed successfully in biomass boiler systems up to now.

<sup>7</sup> Unfortunately the refurbishment of the heating system and the installation of the metering equipment couldn't be finished until March 2009.



**Figure 3: Progress of the monthly use efficiencies<sup>8</sup> of 12 Austrian BOILEff installations including eight gas condensing systems (orange lines), two oil condensing systems (brown lines), one pellets system (light green line), one firewood system (dark green line) [8]**

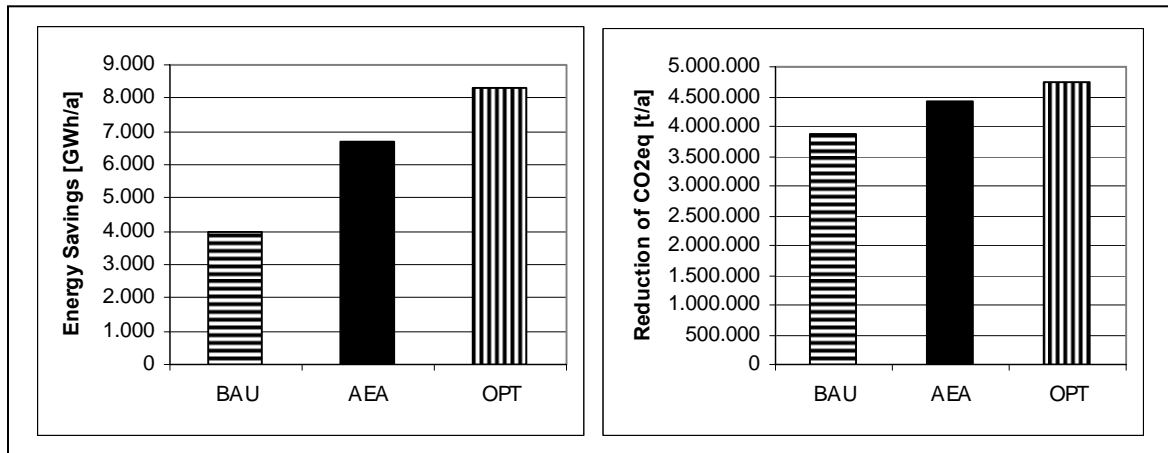
Compared to seasonal efficiencies of standard systems, the first metering results of BOILEff installations show excellent performance. The BOILEff systems achieve efficiency improvements – compared to standard systems – for gas systems of 13 %, for oil systems of 10 %, for the pellets system of 17 %, and for the firewood system of 7 %.<sup>9</sup>

Presently, the total energy demand for heating and domestic hot water amounts to 62.545 GWh in Austria. Taking into account that new heating systems follow BOILEff quality criteria (DHQUI) energy savings between 2.700 and 4.300 GWh can be achieved compared to a business as usual (BAU) scenario; representing a savings potential between 6,4 and 13,3 % (see Figure 4).

The possible savings in greenhouse gases are between 3,85 and 4,74 Mio t. Compared to the BAU scenario 0,6 Mio t (AEA scenario) and 0,9 Mio t (OPT scenario) can be realised (see Figure 4). Space heating contributes significantly – with about 14,2 Mio t. CO<sub>2</sub>eq. or 15,6 % – to the total green house gases of about 91,1 Mio. t. For this reason policy measures aiming to improve heating systems are strongly recommended and these measures will pay-off in significant reductions of green house gases.

<sup>8</sup> The seasonal efficiencies of gas and oil fuelled systems are based on the higher heating value (HHV). The seasonal efficiencies of biomass fuelled boilers are based on the lower heating value (LHV) because the condensing technology has not been deployed successfully in biomass boiler systems up to now.

<sup>9</sup> Seasonal efficiencies of standard installations in Austria are: gas - 76 % (HHV); oil - 75 % (HHV), pellets - 74 % (LHV), firewood - 67 % (LHV) [10].



**Figure 4: Energy savings (left side) and reduction of CO2eq. per year in Austria based on three scenarios [11]:**

- 1) **BAU – business as usual:** The present stock will be replaced by new standard heating systems
- 2) **OPT(imum) scenario:** The present stock will be replaced by new high efficient BOILeff installations
- 3) **AEA scenario:** The present stock will only be replaced partly by high efficient BOILeff systems taking into account appropriate building categories, principal agent problems, fuel switch, etc., the other part will be replaced by new standard heating systems

## Conclusion

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

The high quality declaration (DHQUI) contains a set of quality criteria for a high quality installation of the heating system. This declaration should become part of quotations from installers when selling new installations. The second one – the performance guarantee – 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; usually 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 for the society by increasing the security of supply, by decreasing the import dependency from fossil fuels and by the reduction of greenhouse gases.

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 12 Austrian cases. Compared to seasonal efficiencies of standard systems BOILeff installations show improvements of the seasonal efficiency between 7 % and 17 % depending on the fuel used. Taking into account that new heating systems follow BOILeff quality criteria (DHQUI) energy savings between 2.700 and 4.300 GWh can be achieved compared to a business as usual (BAU) scenario It is expected that these preliminary results will be confirmed by the final evaluation in July 2009 (including the test results of the project partners Germany, Hungary, Spain and Greece).

Furthermore, in some countries like Austria it is foreseen that the implementation of the declaration of high quality installation (DHQUI) is also used as additional subsidy criteria when launching boiler exchange programs. 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 and contribute to 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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