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BOILEFF
Raising the efficiency of boiler installations

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WP 6.1 – Technical evaluation report

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Content

1 Introduction

Although new boilers achieve high efficiency under laboratory conditions, their real performance often is much lower due to improper installation. This was one of the results of the German research project "Optimus" [1] which dealt with the optimization of installed heating systems. The conclusions of a field test carried out in Germany in order to evaluate the operation of gas fuelled condensing boilers [2] were quite similar. Based on the finding that many boiler installations suffer from serious shortcomings, the BOILeff project was initiated to develop and to assess two new market approaches in order to improve the efficiency of boiler installations.

The first market approach is the "Declaration of High Quality Installation" (DHQUI). 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 called "Guaranteed Performance Quality" (GPQU). The installer is supposed to guarantee a certain seasonal efficiency of the boiler if installed according to the DHQUI. DHQUI and GPQU were introduced and explained in WP 3 resp. 4.

Both approaches were tested under real conditions in work package 5. The outcomes of this work package were summarised by four deliverables:

D5.1 – Summary report about field testing
D5.2 – List of participating boiler owners
D5.3 – List of boilers and consumed energy before the replacement
D5.4 – Documentation of field test results

This report builds up on the achieved results of work package 5 and gives a detailed description and evaluation of the results of the test cases. In section 2, the gained data sets from all project partners are compiled and reviewed concerning the implementation of the different quality criteria of DHQUI and of the calculation and metering methods used. In section 3, the technical analysis is carried out. The main emphasis was put on the accuracy and improvement of the guarantee formula (GPQU), the achieved energy and CO_2eq savings and on causal interrelation of heating system parameters like heat load, overdimensioning, type of boiler, efficiency, etc. to further improve the quality criteria of DHQUI and the parameters of GPQU.

2 Review of data sets from field testing

In the field test of the five participating countries the heating systems were installed according to the following quality attributes (see DHQUI; BOILeff WP 3):

1.) Boiler and regulation system:

- Dimensioning of the boiler according to a heat load calculation and a calculation of the domestic hot water demand using the national standards.
- Implementation of a boiler with low standby losses and a high efficiency (e.g. condensing boiler).

2.) Heating water pump:

- Performance of a (at least approximate) calculation of the piping network to dimension the heat pump properly.
- Application of continuous RPM-regulated energy efficient EC-pumps for the regulation of the differential pressure, as far as they are external or exchangeable.

3.) Domestic hot water system:

- Application of an optimally insulated storage tank.

4.) Heat distribution and dissipation:

- Insulation of all pipes, armatures, pumps, storage tanks, and of the boiler.
- Implementation of a hydraulic balance of the system.
- Implementation of a room by room temperature regulation (e.g. thermostats).

In order to quantify the benefits on the seasonal efficiency by installing heating systems according to the DHQUI, i.e. to compare the efficiencies of these high quality systems with those of the present stock, heat meters were integrated.

In Austria standard heating systems show an average seasonal performance – based on the total boiler stock – of [3]:

gas: 76% (HHV),
oil: 75% (HHV),
pellets: 74% (LHV),
firewood: 67% (LHV).

For the other countries no average values were either available or could be identified.

By the GPQU the installer shall guarantee a certain seasonal performance quality to the customer. Several guarantee concepts (and formulas) for the seasonal efficiency of boilers have been introduced. The different concepts are described in Deliverable 4.2 [4] and in [5]. Based on the discussions within the stakeholder meetings consensus was achieved to use the most – for the installer – user-friendly concept. The formula takes into account the following characteristics of the heating systems:

- Installation of the boiler inside or outside the heated area,
- Boilers whether with or without a bypass valve,

- Distinction between oil and gas boilers:

$$\eta_a(\beta=0{,}1) = 90\% * (1 - 3\%*O) * (1 + 4\%*I) * (1 - 3\%*V), \qquad \text{eq. (1)}$$

with η_a seasonal efficiency dependent on the average workload β (standard = 10%)

O = 1	for oil condensing	*O* = 0	for gas condensing boilers,
I = 1	for boilers inside	*I* = 0	for boilers outside the heated area,
V = 1	for boilers with	*V* = 0	for boilers without a bypass valve.

In the following this formula is called “GPQU formula 1”.

According to the results of the Austrian field test the formula was refined by an additional term taking into account the type of the heat dissipation system:

$$\eta_a = 89\% * (1 - 3\%*O) * (1 + 4\%*I) * (1 - 3\%*V) * (1 - 1{,}5\%*W), \qquad \text{eq. (2)}$$

with

W = 1 for radiators and *W* = – 1 for floor or wall heating;

for the other abbreviations see eq. (1). For test cases with radiators and floor heating *W* has either to be calculated with a weighted average or set to *W* = 0. In the Austrian field test the average workload was identified to have no effect on the seasonal efficiency. Hence, this dependency was dropped. This formula is called “GPQU formula 2”.

In the following the results of the project partners regarding key data and measurements of the test cases are shown.

Germany

The following table shows the key data of the six German test cases.

Table 1: Key data of the German test cases (Source. Austrian Energy Agency based on data sets from Wuppertal Institute)

Nr.	Type of building	Heating system	Heat load of the build-ing/flat [kW]	Measured efficiency [%]	Calculated efficiency by GPQU formula 1 [%]	Calculated efficiency by GPQU formula 2 [%]
DE 1	single family house	Wall mounted condensing gas boiler	11,5	78,1	87,3	85,0
DE 2	single family house	Floor standing condensing gas boiler + solar + firewood	14,2	77,3	90,0	87,7
DE 3	multi family house	Floor standing low tempera-ture oil boiler	24,0	80,5	N.A.	N.A.
DE 4	single family house	Floor standing condensing gas boiler	24,2	60,1	90,0	87,7
DE 5	single family house	Floor standing condensing gas boiler + solar + firewood	9,3	89,0	90,0	88,3
DE 6	multi family house	Floor standing firewood and pellets boiler + solar	29,0	56,0	N.A.	N.A.

Both GPQU formulas are neither applicable to low temperature boilers nor to biomass boilers.

The following remarks have to be made to the German test cases:

Test case 1: The achieved seasonal efficiency is much lower than the average metered values of gas condensing boilers in the German field test study [2]. Taking into account the lower efficiency in summer, the measured efficiency will decline to about 77%. According to [2] the average efficiency of a low temperature boiler is 75,5% and the average gas heating system in Austria shows a performance of 76% [3]. For this reason it has to be assumed that the boiler works like an average low temperature model and the quality criteria of the DHQUI have only partly or not been fulfilled. According to the German project partner the reason for the low efficiency seems to be the high return flow temperature caused by too small radiators. Due to the high return flow temperature a condensation of the exhaust gas was not possible and the efficiency of the boiler dropped down to the efficiency of a usual low temperature boiler.

Test case 2: The boiler is directly integrated into the hot water storage tank which is additionally supplied by a solar system. For this reason it is not possible to measure the energy output of the boiler without taking into account the solar system and the stand-by losses of the hot water storage tank. This means a system efficiency and not a boiler efficiency was calculated. The applied measurement concept is not conform with D 4.1. However, the achieved seasonal efficiency has to be judged in anyway as very low for a condensing boiler.

Test case 3: The used oil boiler is a low temperature boiler. One of the main quality criteria of the DHQUI is the implementation of a highly efficient boiler. Since condensing boilers are available on the market for the combustion of oil and gas, low temperature boilers do not fulfil the DHQUI-criteria. Still it has to be remarked that this low temperature oil boiler shows a better efficiency than the condensing gas boilers of test cases 1 and 2.

Test case 4: A malfunction of the implemented metering equipment leads to useless metering results. The reason for the malfunction is a wrong installation of the metering equipment by the installer.

Test case 5: similar to test case 2; furthermore the metering period started on April, 2nd and ended on July, 2nd. Therefore neither a seasonal efficiency nor an annual energy consumption can be calculated without making rough estimates.

Test case 6: In total, three biomass boilers took part in the European field tests (two in Austria and one in Germany). In every test case a different boiler technology was used. A wood gas powered boiler and a low temperature pellets boiler were evaluated in Austria. Test case 6 from Germany represents an individually combined pellets and firewood boiler system. Subsequently, the achieved results of biomass boilers are not comparable; furthermore the achieved efficiency of test case 6 has to be judged as very low.

Hungary

The following table shows the key data of the 10 Hungarian test cases. In all of them a gas heating system was installed. The test cases taken into account for the evaluation are written in bold letters.

Table 2: Key data of the Hungarian test cases (Source: Austrian Energy Agency based on data sets from Innoterm)

Nr.	Type of building	Heating system	Heat load of the build-ing/flat [kW]	Measured efficiency [%] based on HHV	Calculated efficiency by GPQU formula 1 [%]	Calculated efficiency by GPQU formula 2 [%]
HU 1	**single family house**	**Wall mounted condens-ing gas boiler**	**20,0**	**93,4**	**90,8**	**91,1**
HU 2	**single family house**	**Wall mounted condens-ing gas boiler**	**23,4**	**90,1**	**87,3**	**87,6**
HU 3	**single family house**	**Wall mounted condens-ing gas boiler**	**15,0**	**88,9**	**87,3**	**86,3**
HU 4	Office building	Wall mounted condensing gas boiler	40,0	87,2	87,3	86,3
HU 5	**single family house**	**Wall mounted condens-ing gas boiler**	**16,2**	**83,8**	**87,3**	**86,3**
HU 6	**single family house**	**Wall mounted condens-ing gas boiler**	**12,0**	**80,7**	**87,3**	**86,3**
HU 7	**single family house**	**Wall mounted condens-ing gas boiler**	**20,0**	**80,0**	**87,3**	**85,0**
HU 8	single family house	Wall mounted low temperature gas boiler	24,0	77,5	N.A.	N.A.
HU 9	single family house	Wall mounted low temperature gas boiler	12,0	76,1	N.A.	N.A.
HU 10	single family house	Wall mounted atmos-pheric gas boiler	35,0	75,1	N.A.	N.A.

For the technical evaluation, 6 of the 10 gas heating systems were taken into account. The 4 remaining systems could not be taken into account due to the following reasons:

Test case 4 is an office building. The BOILeff project concentrated on residential buildings. An office cannot be compared with residential buildings because of different types of usage, especially regarding hot water demand and occupation times. Furthermore the heat load amounts to 40 kW which is far above the limit of 20 – 25 kW of typical households. Anyway, quite a decent efficiency could be achieved in this test case.

Test cases 8 to 10: The used boilers are low temperature boilers. One of the main quality criteria of the DHQUI is the implementation of a highly efficient boiler. Furthermore, the applied GPQU concept (and formula) takes into account only condensing boiler systems. Moreover, the heat load of test case 10 is too high.

Austria

13 heating systems were equipped with heat meters. 9 of the boilers run with natural gas, 2 with oil, 1 with wood pellets, and 1 with firewood. 4 of the gas boilers, the pellets and the firewood boiler are supported by solar thermal collectors which are metered separately. 2 of the test cases are flats, 1 is a small multi family house; the other 10 are single family houses.

The following table shows the key data of all 13 Austrian test cases.

Table 3: Key data of the Austrian test cases (Source: Austrian Energy Agency)

Nr.	Type of building	Heating system	Heat load of the building/flat [kW]	Measured efficiency [%]	Calculated efficiency by GPQU formula 1 [%]	Calculated efficiency by GPQU formula 2 [%]
AT 1	**flat**	**Wall mounted condensing gas boiler**	**13,1**	**86,7**	**90,8**	**88,4**
AT 2	**flat**	**Wall mounted condensing gas boiler**	**4,9**	**87,8**	**90,8**	**88,4**
AT 3	single family house	Wall mounted condensing gas boiler	11,4	N.A.	87,3	87,6
AT 4	**single family house**	**Floor mounted condensing gas boiler**	**4,7**	**82,4**	**87,3**	**85,0**
AT 5	**small multi family house**	**Floor mounted condensing gas boiler + solar**	**22,0**	**94,8**	**93,6**	**91,9**
AT 6	**single family house**	**Wall mounted condensing gas boiler**	**5,8**	**87,5**	**87,3**	**85,0**
AT 7	**single family house**	**Wall mounted condensing gas boiler + solar**	**11,2**	**91,3**	**90,0**	**89,5**
AT 8	single family house	Floor mounted wood gas boiler + solar	4,2	74,2	N.A.	N.A.
AT 9	**single family house**	**Wall mounted condensing gas boiler + solar**	**7,5**	**88,8**	**90,0**	**89,0**
AT 10	single family house	Floor mounted condensing oil boiler	9,8	84,2	87,3	85,0
AT 11	**single family house**	**Floor mounted condensing gas boiler**	**12,0**	**89,8**	**90,0**	**90,3**
AT 12	single family house	Floor mounted condensing oil boiler	8,3	85,9	87,3	85,0
AT 13	single family house	Floor mounted pellets boiler + solar	11,0	90,6	N.A.	N.A.

The measured efficiency for test cases 8 and 13 is based on LHV, else on HHV. In test case 3 the metering equipment was installed too late; the GPQU formula is not applicable to biomass boilers at the moment, so there are no calculated values in test cases 8 and 13.

As already pointed out the results of the biomass boilers (due to different fuels and boiler technologies) are not comparable. Moreover there are only 3 oil boilers which could be taken into account (2 in Austria, 1 in Germany) which is not enough as well. Consequently, in-depth analysis was performed taking into account only the gas heating systems. In 1 of 9 Austrian gas systems the metering equipment was implemented too late; so there are 8 Austrian heating systems to be taken into account for the analysis.

Spain

Heating systems according to the DHQUI were implemented in 14 test cases, two of them are large multi family houses with heat loads of 150 resp. 250 kW. 11 of the 12 remaining test cases are single family houses, 1 is a flat.

9 of the 14 heating systems run with natural gas, 2 with pellets, 2 with gasoil, 1 with propane. All gas heating systems are equipped with condensing technology.

For the GPQU a seasonal efficiency of 85% for all test cases was guaranteed. Unfortunately no metering results are available due to the lack of heat meters. For this reason no Spanish results were taken into account for the analysis.

Greece

Greece succeeded to implement 200 heating systems following DHQUI quality criteria. However, end-consumers could not be convinced to participate in the field testing due to the specific frame conditions in Greece.

Summary of the gained data sets

Finally, only the Austrian, the German and the Hungarian project partners produced metering results. In total 23 gas heating systems, 3 oil heating systems and 3 biomass heating systems were measured. Due to the low number of heating systems with oil and different technologies (and fuels) with biomass, for comparison reasons, only the results of the gas heating systems received an in-depth analysis.

6 gas heating systems (3 in Germany, 3 in Hungary) show too low efficiency values indicating that the DHQUI quality criteria were not fulfilled sufficiently (e.g. low temperature instead of a condensing boiler); the metering of 2 systems (1 in Germany, 1 in Austria) started in April 2009 which was a too short time for evaluation; 1 system (in Hungary) was installed in an office building having other load characteristics than typical households.

Finally, 14 gas heating systems (8 Austrian and 6 Hungarian test cases) fulfil the quality criteria of DHQUI and other specifications; these systems were used for the in-depth analysis.

3 Technical analysis

The following quality criteria of the DHQUI have been implemented into the 14 gas heating systems: condensing technology, hydraulic balance, heat load calculation, calculation of the hot water demand, optimally adjusted energy efficient pump, insulation of distribution pipes in the unheated area according to the country specific standards.

The measured efficiency data of 14 gas heating systems (8 in Austria, 6 in Hungary) and the two GPQU formulas introduced in the previous chapter are analyzed in the following section.

3.1 Accuracy of the GPQU formulas

An important task of the whole BOILeff project was to create methods to forecast seasonal efficiencies of boilers. Therefore the two GPQU formulas were developed, as explained in the previous chapter (see also [4], [5]). In this report the accuracy of these formulas is evaluated on the basis of the results of the transnational field test. The following table shows the key data for this analysis.

Table 4: Efficiency of the 14 gas heating systems in comparison to the forecasted values of the two GPQU formulas (Source: Austrian Energy Agency)

Nr.	Measured efficiency [%] based on HHV	Calculated efficiency by GPQU formula 1 [%]	Calculated efficiency by GPQU formula 2 [%]	Deviation of metered value from GPQU 1 [%]	Deviation of metered value from GPQU 2 [%]
HU 1	93,4	90,8	91,1	2,6	2,3
HU 2	90,1	87,3	87,6	2,8	2,5
HU 3	88,9	87,3	86,3	1,6	2,6
HU 5	83,8	87,3	86,3	-3,5	-2,5
HU 6	80,7	87,3	86,3	-6,6	-5,6
HU 7	80,0	87,3	85,0	-7,3	-5,0
AT 1	86,7	90,8	88,4	-4,1	-1,7
AT 2	87,8	90,8	88,4	-3	-0,6
AT 4	82,4	87,3	85,0	-4,9	-2,6
AT 5	94,8	93,6	91,9	1,2	2,9
AT 6	87,5	87,3	85,0	0,2	2,5
AT 7	91,3	90,0	89,5	1,3	1,8
AT 9	88,8	90,0	89,0	-1,2	-0,2
AT 11	89,8	90,0	90,3	-0,2	-0,5

The GPQU formula 1 [4] was created by means of the results of [2]. It shows a mean deviation of 2,89% from the metered values. The GPQU formula 2 was adapted according to the Austrian field test results [5]. The mean deviation, also after including the Hungarian results, is reduced to 2,38%. The GPQU formula 2 shows deviations of more than 3% in five cases, the GPQU formula 2 in only two cases which also indicates that the GPQU formula 2 is more reasonable. The following graph shows the deviations of the metered values from the two GPQU formulas mentioned in Table 4.

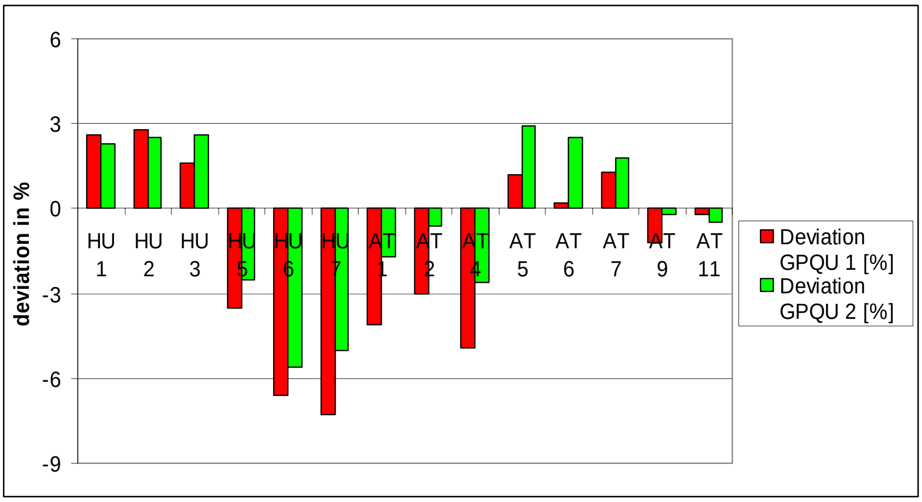

Figure 1: Deviations of the metered seasonal efficiencies from the forecasted value; a positive value indicates that the heating system performed better than forecasted by the GPQU formula; for the abbreviations see Table 4 (Source: Austrian Energy Agency)

The 8 Austrian test cases evaluated in this report show a maximum deviation of 3 percentage points of the determined seasonal efficiency from the calculated value by the GPQU formula 2. Due to this fact for Austrian heating systems installed according to the DHQUI a security band for the guaranteed seasonal efficiency of 3 percentage points can be considered. Unfortunately two Hungarian test cases show a negative deviation of 5% resp. 5,6%. Accordingly for Hungary a larger security band (up to 6%) must be suggested.

3.2 Energy and CO_2eq savings

In this section, the efficiencies as well as the energy and CO_2eq savings and the workloads of the 14 gas heating systems are shown in bar charts.

In the Hungarian test cases the climate corrected annual energy consumption was reduced by 44.397 kWh (7.400 kWh per test case), in Austria the reduction amounts to 62.311 kWh (7.789 kWh per test case). In total, energy savings of 106.708 kWh (7.622 kWh per test case) could be achieved, which is a reduction of almost 25% (see Figure 2).

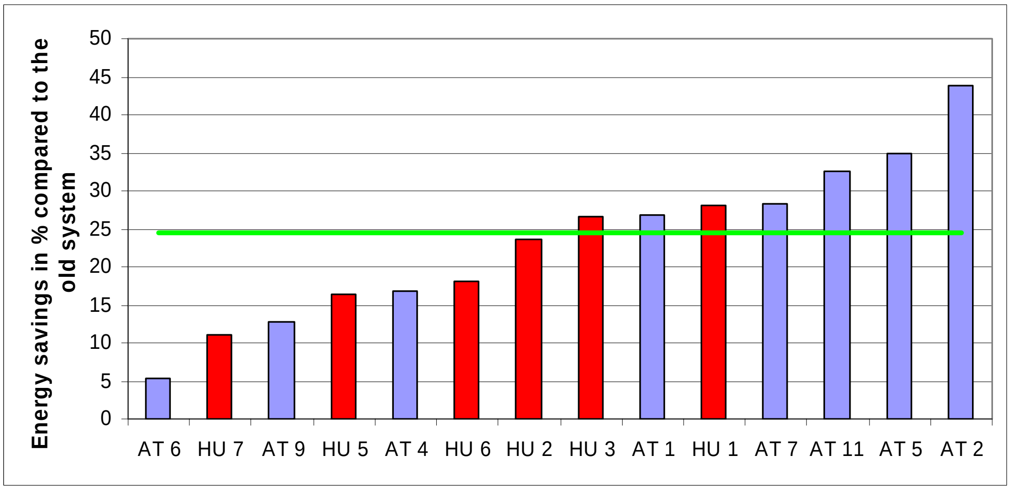

Figure 2: Energy savings in % compared to the old systems; the 6 Hungarian results are coloured red, the 8 Austrian are blue; the green line indicates the average savings; for the abbreviations see Table 4 (Source: Austrian Energy Agency)

The CO_2eq emissions of the Hungarian test cases were reduced by 8.441 kg/a (1.407 kg/a per test case), in Austria the reduction amounts to 15.765 kg/a (1.971 kg/a per test case). In total, the CO_2eq savings amount to 24.206 kg/a (1.729 kg/a per test case), which is an average reduction of almost 30% (see Figure 3).

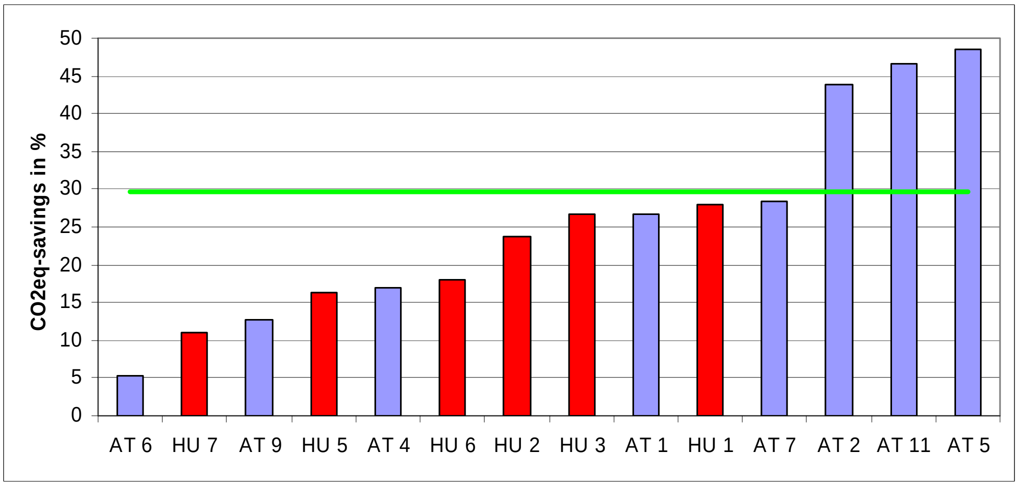

Figure 3: CO_2eq savings in % compared to the old systems; the 6 Hungarian results are coloured red, the 8 Austrian are blue; the green line indicates the average savings; remark: due to the weighted average (test cases with higher energy consumption contribute more) the green line does not seem to be the average, but it is; for the abbreviations see Table 4 (Source: Austrian Energy Agency)

According to Figure 4 the average BOILeff system achieves a seasonal efficiency of 87,9% (HHV; Austria: 89,63%, Hungary: 86,00%). In [2] the average efficiency of a gas condensing boiler is determined to 86,2%, while low temperature gas boilers reach 75,5%.The efficiency of an Austrian standard heating system according to [6] is 83% (LHV) = **75% (HHV)**, in [3] the average gas heating system in the stock performs with a seasonal efficiency of **76% (HHV).** (No values for standard Hungarian systems are available.) Explanations concerning the two lowest efficiency values (HU 7, HU 6) are seen in the small surface of the radiators (following Innoterm). Consequently the return temperature was too high to enable condensation of the exhaust gases. Nevertheless, BOILeff installations following DHQUI quality criteria show significant higher seasonal efficiencies than standard systems.

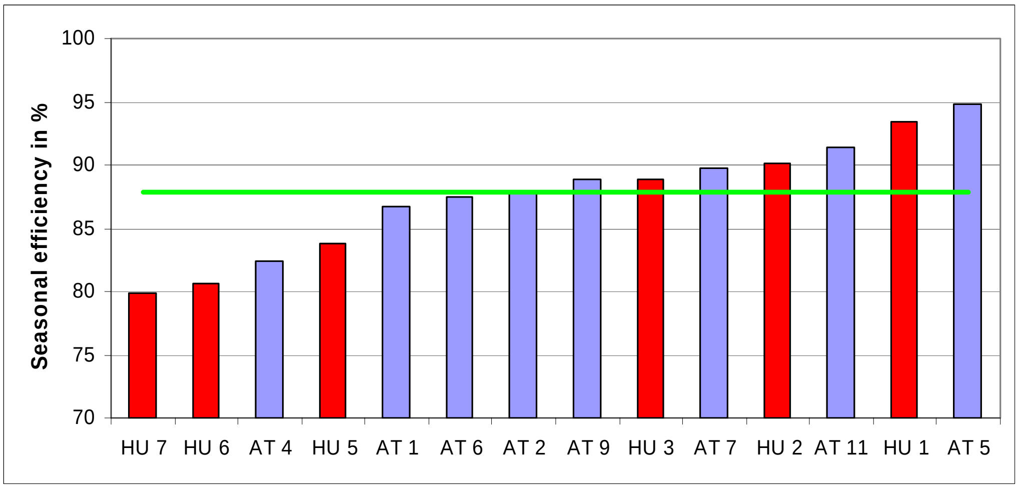

Figure 4: Seasonal efficiencies of the 14 evaluated heating systems of the field test; the average seasonal efficiency is indicated by a green line; the 6 Hungarian results are coloured red, the 8 Austrian are blue; for the abbreviations see Table 4 (Source: Austrian Energy Agency)

The following figure shows the average annual workload of each test case.

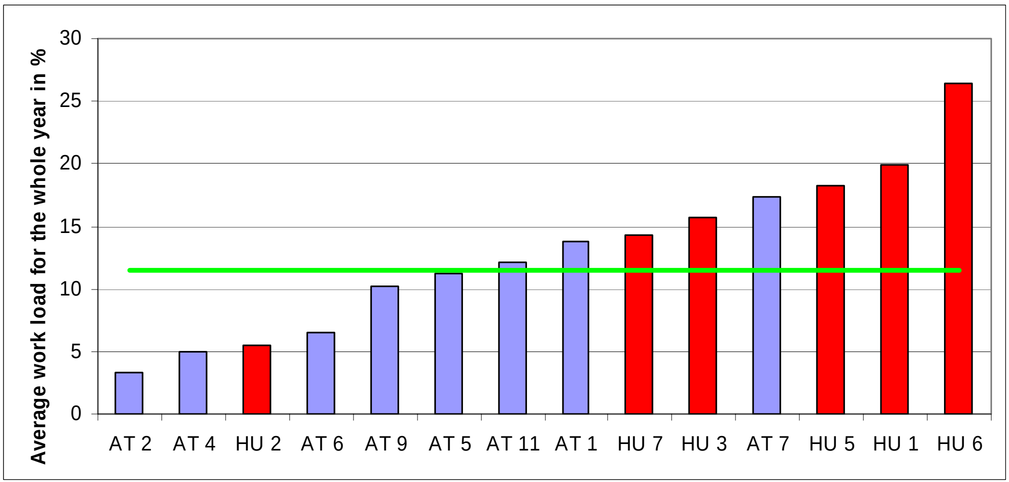

Figure 5: Average workloads extrapolated to the whole year; the 6 Hungarian results are coloured red, the 8 Austrian are blue; the average workload is indicated by a green line; for the abbreviations see Table 4 (Source: Austrian Energy Agency)

In [2] the average work load of the tested gas condensing boilers was determined to 9%. The BOILeff heating systems performed with an average annual workload of 11,5% which is an indicator for an improved dimensioning as a result of a heat load calculation.

3.3 Causal interrelation of heating system parameters

A very important task of this report is to find correlations between various variables like efficiency, workload, heat load, overdimensioning factor, hot water demand, energy consumption, boiler attributes (see GPQU formulas), climate, etc. The most significant results were chosen and included in this section. For an optimal clarity of the correlation between these data sets, the results are shown in scatter diagrams. To most of the graphs a linear approximation was performed to show the tendencies. If a polynomial trendline is more reasonable this type of approximation was added to the graph (e.g. to show maxima which is not possible with a linear approximation). In most cases the Austrian and the Hungarian test cases can be distinguished by different colours as in the previous bar diagrams.

The first graph of this series shows the correlation between the heat loads of the test cases and the metered seasonal efficiencies.

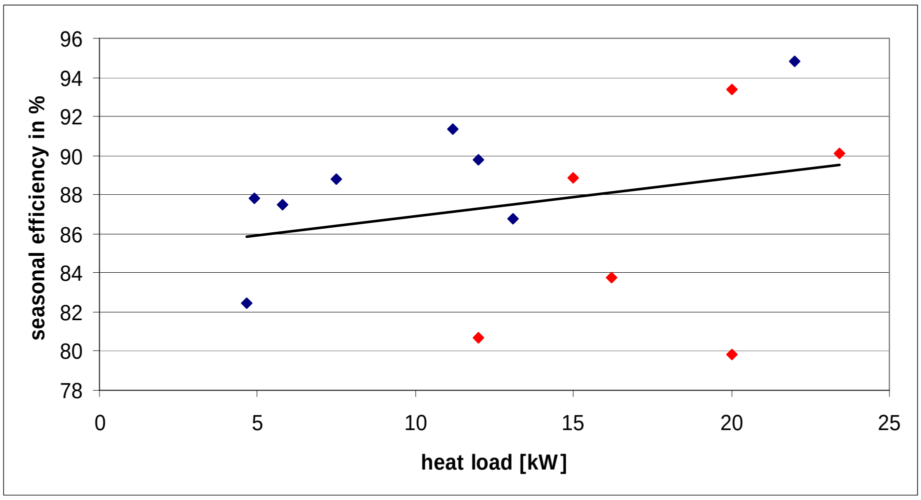

Figure 6: Seasonal efficiency vs. heat load of the 14 gas heating systems installed according to the DHQUI; the 6 Hungarian results are coloured red, the 8 Austrian are blue (Source: Austrian Energy Agency)

The next graph shows the correlation between the average boiler workload and the monthly efficiency. In [2] it was proposed that the efficiency increases strictly monotonic with growing workload. As the graph shows this is not the case with the heating systems of this field test.

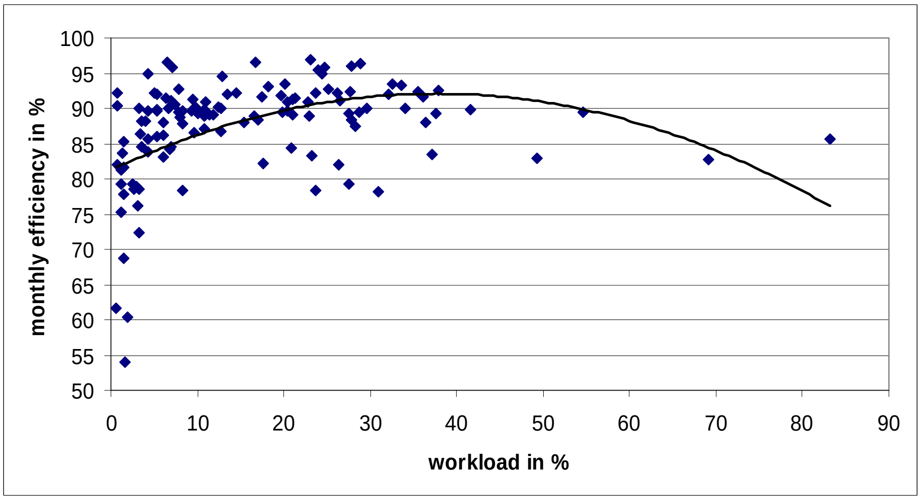

Figure 7: Polynomial approximation of the monthly efficiencies of the 14 gas heating systems (Source: Austrian Energy Agency)

The efficiency maximum is at 37,5%, with higher workloads the efficiency declines again. This seems to be contradicting to [2] where the efficiency was set to be strictly monotonic increasing with the workload. In [2] the highest metered workload is slightly above 43% and there is only a second data point above 40%. The data was just extrapolated to higher workloads by means of a theoretical model. In this field test higher workloads have been achieved which is an indicator for a well performed heat load calculation. Still the number of the data points in the region of 40% and more is low. Further measurements in future field tests should be carried out and to validate this result.

The next graph shows the same correlation, but with annual workloads and efficiencies.

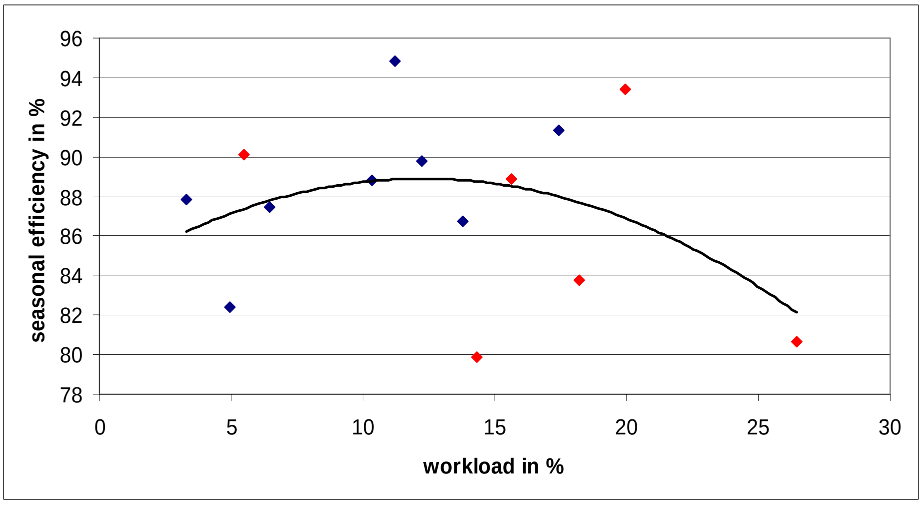

Figure 8: Polynomic approximation of the correlation between average annual workload and the seasonal efficiency; the 6 Hungarian results are coloured red, the 8 Austrian are blue (Source: Austrian Energy Agency)

Somehow this result is according to DIN 4702-8: starting from 13% the seasonal efficiency drops down; still these values are annual workloads while DIN-norm refers to instantaneous workloads.

In the optimal case the results of the BOILeff project should have lead to an additional factor in the GPQU formula taking into account the average annual workload of the system. The next graph shows that this factor would have to reduce the efficiency for higher workloads.

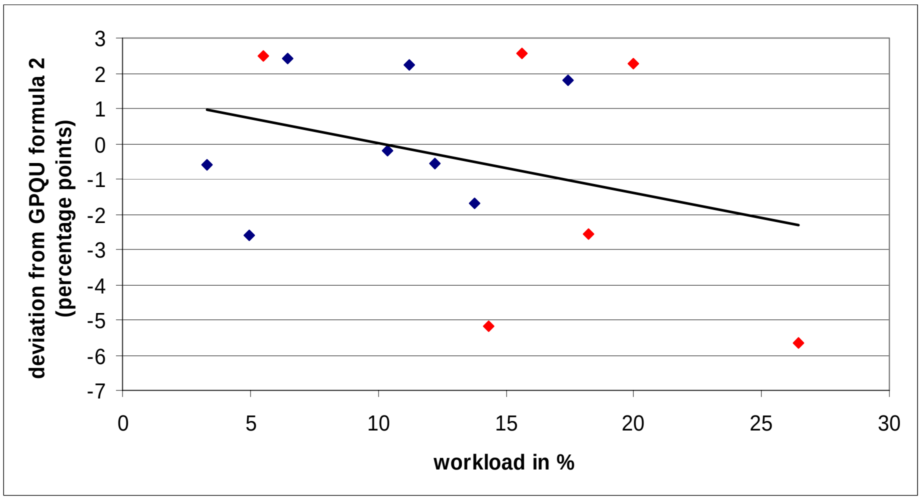

Figure 9: Deviation of the metering results from the forecasted efficiency by GPQU formula 2; the 6 Hungarian results are coloured red, the 8 Austrian are blue (Source: Austrian Energy Agency)

Consequently the additional factor would have to reduce the forecasted efficiency with decreasing workload i.e. if the boiler is dimensioned according to the heat load calculation. Further field tests should show if this result can be reproduced. Two of the test case show very poor performance in comparison to the GPQU formula, indicating that the relevant criteria of the DHQUI have not been performed adequately. The following graph excludes these two heating systems which leads to a completely different result. This figure also shows very well that the GPQU formula 2 always lies within a 3% security band.

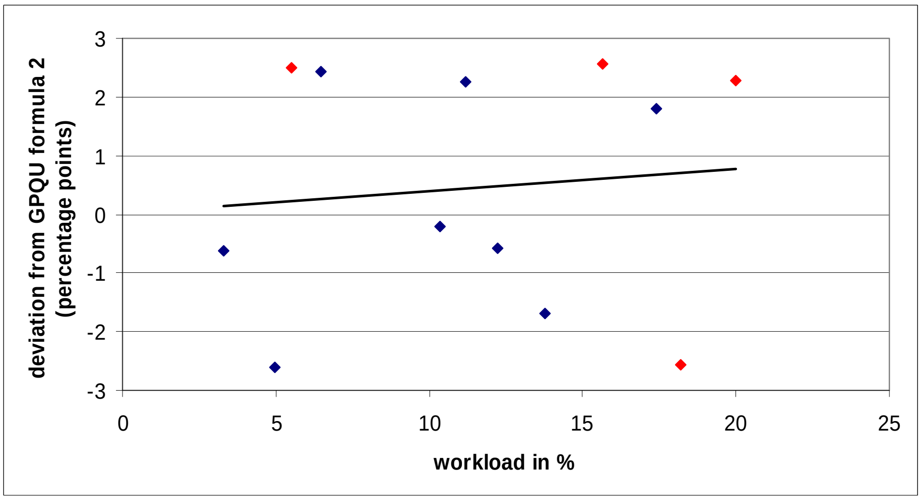

Figure 10: Deviation of the metering results from the forecasted efficiency by GPQU formula 2 without the two systems with too high return temperatures; the 6 Hungarian results are coloured red, the 8 Austrian are blue (Source: Austrian Energy Agency)

This graph indicates that there might be a slightly positive influence of the average annual workload on the efficiency; still this trend is not very strong.

The following graph shows the connection between the nominal boiler capacity and the heat load which indicates the level of overdimensioning. The line indicates the equality of heat load and nominal power output of the boiler which is the optimal case and was achieved in 3 installations. Especially for low heat loads it is sometimes difficult to find a suitable boiler. Still, since boilers are equipped with a modulation feature of the power output, the effect of this problem on the efficiency is reduced. In only two cases it was not possible to install a boiler model whose least continuous power output lies below the heat load.

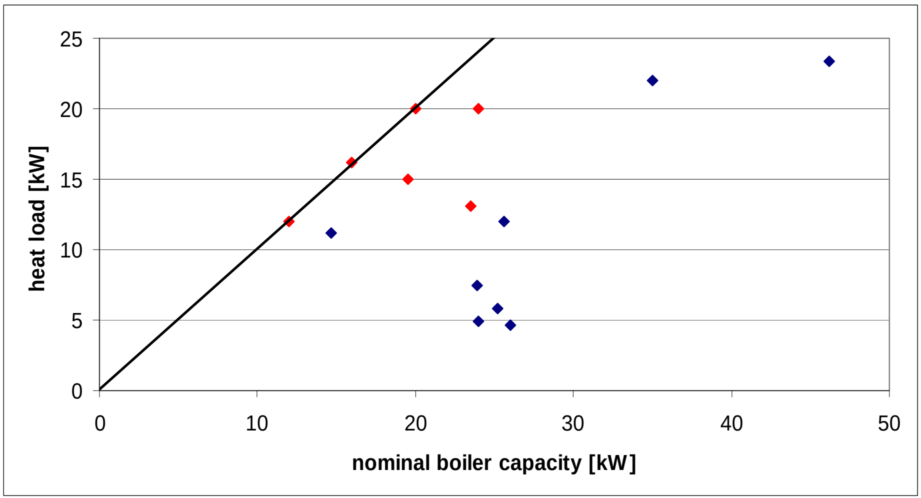

Figure 11: Nominal boiler capacity vs. heat load; the 6 Hungarian results are coloured red, the 8 Austrian are blue (Source: Austrian Energy Agency)

The factor of overdimensioning can be indicated by dividing the nominal boiler capacity by the heat load. The correlation between this ratio and the seasonal efficiency is shown in the next graph.

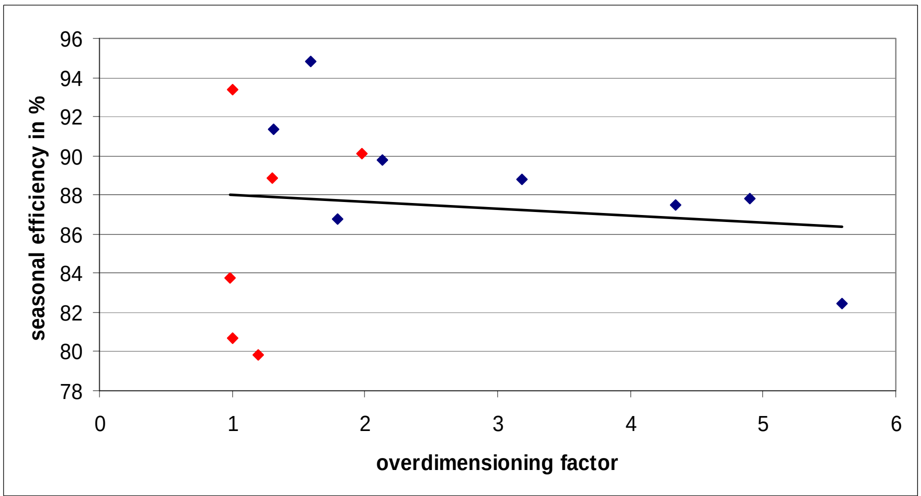

Figure 12: Dependency of the seasonal efficiency of the heating systems on the ratio of nominal boiler capacity and heat load; the 6 Hungarian results are coloured red, the 8 Austrian are blue (Source: Austrian Energy Agency)

Unfortunately, both systems in which too high return temperatures impeded condensation of the exhaust gases to a large extent (efficiencies of about 80%) are dimensioned almost perfectly. This pulls the trendline down towards lower efficiencies on the left side. Still the line shows that a proper dimensioning of the boiler has a positive influence on the efficiency of the system.

The following graph shows that a higher fraction of the domestic hot water on the energy consumption leads to a lower efficiency, according to the results of [2]. This can be explained by the fact that (especially in systems with floor heating) a higher flow temperature is needed for the hot water which reduces the efficiency.

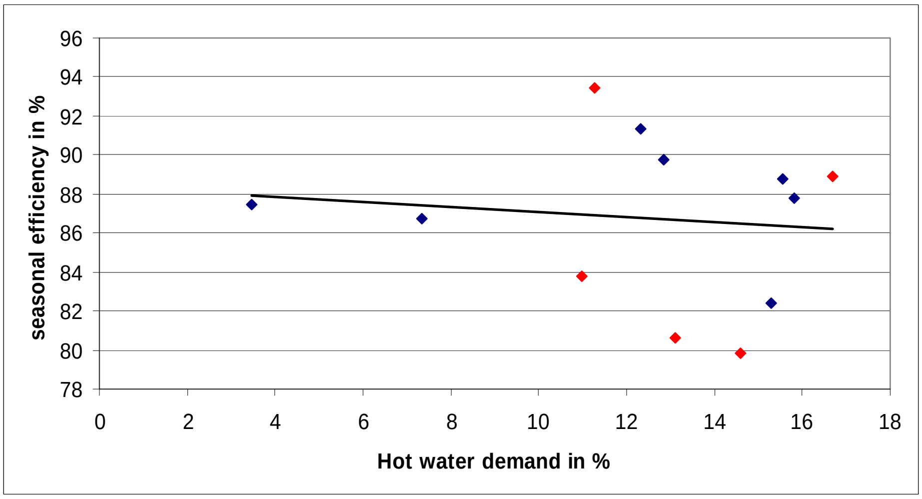

Figure 13: Seasonal efficiency vs. fraction of the energy consumption for domestic hot water; the 6 Hungarian results are red, the 8 Austrian are blue; there are only 12 data points, because in 2 test cases the domestic hot water demand could not be metered separately due to technical reasons but only together with the heating (Source: Austrian Energy Agency)

A further important result is documented by the following graph: The average workload of the boilers in the field test increases with the energy demand. The conclusion can be drawn that smaller boilers are overdimensioned more which can be caused by the fact that installers did not care if a test case had a low heat load or there was no suitable boiler model.

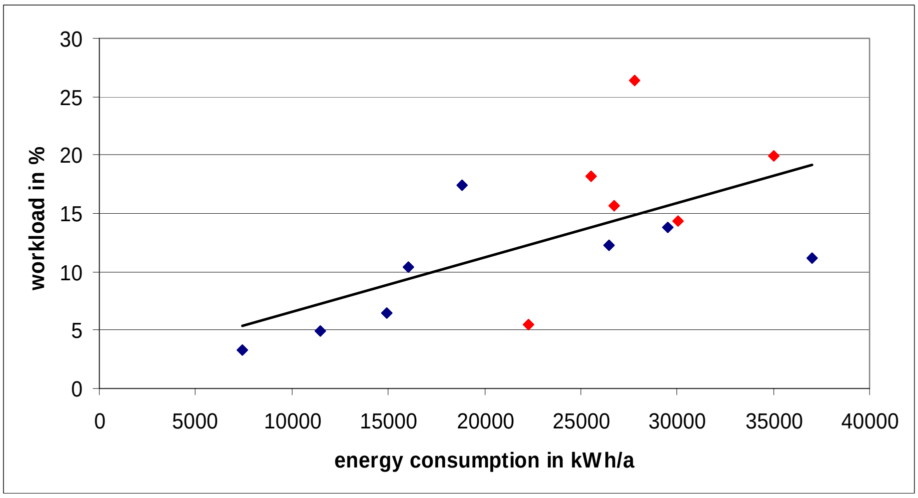

Figure 14: Connection between the annual energy consumption and the average annual workload; the 6 Hungarian results are red, the 8 Austrian are blue (Source: Austrian Energy Agency)

According to the results of [2] and of the Austrian field test in GPQU formula 2 three attributes were identified that influence the seasonal efficiency of gas heating systems: (i) heat dissipation system, (ii) positioning of the boiler whether in the heated or in the unheated area, (iii) existence or absence of a bypass valve. The following figure shows the dependency of the boiler efficiency on these characteristics; furthermore the positive influence of solar thermal systems is shown.

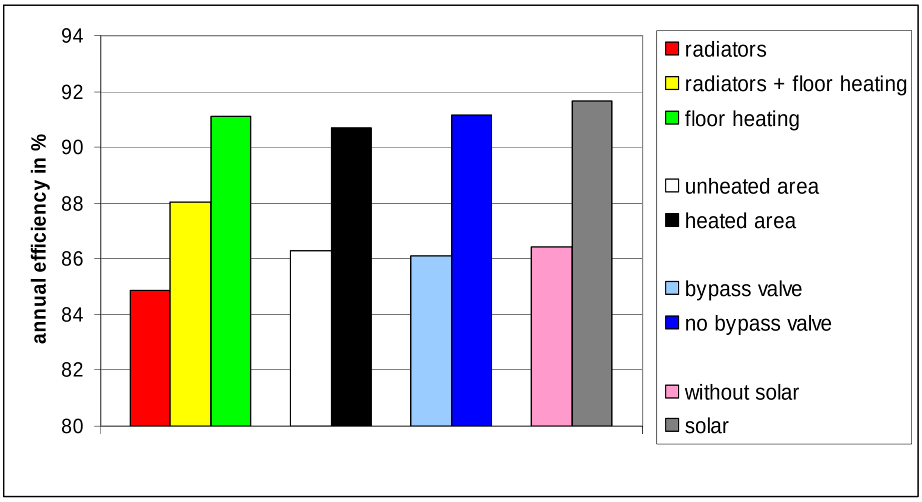

Figure 15: Influence of the heat dissipation system, the position and the type of the gas boiler as well as of a supporting solar thermal system on the seasonal efficiency (Source: Austrian Energy Agency)

Accordingly the dependencies of the efficiency according to the GPQU formula can be confirmed:

- Heating systems show a 4,3% higher efficiency if the boiler is placed in the heated area (and not in the unheated area) due to lower storage losses.
- The benefit of a floor heating is determined to 6,2% compared to a radiator heating system.
- The heating systems without a bypass valve show a 5% higher efficiency than those with.
- A solar thermal system reduces the losses in summer (caution: all (3 of 14) solar systems are connected with boilers without bypass valve, this might enlarge the difference); [2] resumed

that there is almost no influence of solar thermal collectors on the efficiency; a larger number of test cases with a solar thermal system would have been necessary to verify this effect.

At this stage it should be noted that in each of the 4 cases the influences of the other 3 attributes also play a role. Subsequently, the differences shown in the figure cannot be taken into a formula constructed as those of the both GPQU formulas; therefore the influence of each criterion would have to be separated which is not possible for 14 metering points and 4 criteria. This leads to the fact that e.g. if there are more solar thermally supported heating systems without than with bypass valve (which is the case in this field test) the apparent influence of solar heat (which is shown) is enlarged by the influence of the absence of a bypass valve; if there were more solar thermally supported heating systems with than without bypass valve, the apparent correlation would be smaller than the real influence – always including the assumption that the other two criteria are distributed equally. Within a larger field test these influences could be separated which would allow to improve the GPQU formula.

Furthermore the results could have been evaluated in respect to the climate. Unfortunately the two South European partners could not provide metering results. Hungary and Austria show a quite similar climate: The numbers of the heat degree days only differ slightly (app. between 2.800 and 3.400); so the dependency of the efficiency or other parameters on the weather could not be evaluated: The average heat degree days per year (in Kd/a) are: Vienna city centre: 2.744, suburbs: 3.048, Linz: 3.267; (Düsseldorf: 2.902); Budapest: around 3.400. Under the given circumstances the results of a possibly given connection between seasonal efficiency and heat degree days would be overlapped by other influence factors.

The efficiency of the heating systems is almost independent of the specific heat load (heat load per m²) as shown by the following graph.

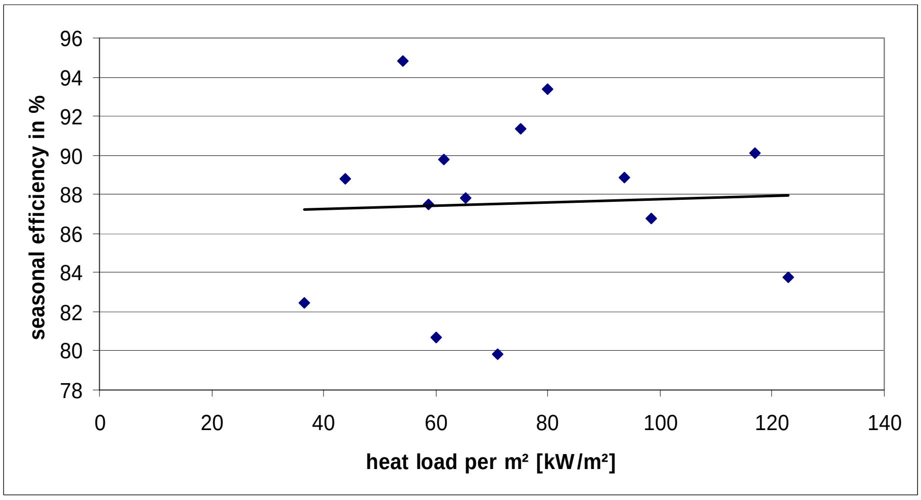

Figure 16: Correlation between heat load and seasonal efficiency; the 6 Hungarian results are coloured red, the 8 Austrian are blue (Source: Austrian Energy Agency)

In principle it could have been suggested that a higher heat load per m² leads to lower distribution losses because the heat transport runs over shorter distances (There is an analogue effect with district heating: If the objects to be heated are situated very closely together (high energy demand per area) the distribution losses decline.) Nevertheless, the graph shows only a little dependency. Possibly this effect does not play a role on a small scale of a flat or a house; moreover it could indicate that the insulation of the pipes in the test cases impeded distribution losses to a large extent.

4 Summary – Conclusion

Insufficient installation of heating systems often leads to low efficiency of new – even condensing – boilers. Although test cases demonstrate that new boilers may achieve high efficiency, their real performance is often much lower. 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 (DHQUI). 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 (GPQU)”. The installer should be able to guarantee a certain efficiency of the boiler as a result of a “high quality installation”.

These two approaches were tested and evaluated by field tests under real conditions in the heating period 2008/2009. For the field tests, typical residential buildings with heat loads up to 20 to 25 kW have been taken into account.

About 50 installations in Austria, Germany, Hungary, Spain, and Greece were foreseen to participate in the field tests in the heating season 2008/2009. In total, metering results were achieved in 23 gas heating systems, 3 oil heating systems and 3 biomass heating systems in Austria, Germany and Hungary. Due to the low number of heating systems with oil and different biomass technologies (and biomass fuels), for comparison reasons, the in-depth analysis was only carried out for gas heating systems.

In average, the gas heating systems achieved a seasonal efficiency of 87,9% (HHV), the two oil heating systems 85,0% (HHV), the pellets system 90,6% (LHV) and the firewood boiler 74,2% (LHV). BOILeff installations outperform standard systems (stock consideration) by 11,9 (gas), 10,0 (oil), 16,6 (pellets) resp. 7,2 (firewood) percentage points.

In-depth analysis of 14 gas heating systems showed annual energy savings of 106.708 kWh; including the 2 oil and the 2 biomass systems the savings accumulate to 140.206 kWh. This corresponds to CO_2eq-savings of 24.206 kg/a resp. 38.420 kg/a. In Austria the theoretical savings potential by substituting the total heating system stock by DHQUI-systems amounts to 8.300 GWh/a or 4,74 Mio. t CO_2eq emissions.

The analysis shows that the GPQU method (formula) can forecast the efficiency within a security band of 3 percentage points in Austria and of 6 percentage points in Hungary. The following parameters contribute positively to the seasonal efficiency: (i) boiler is placed in the heated area, (ii) boiler has no bypass valve, (ii) heat dissipation by floor heating system, and (iv) additional solar thermal system. Positive correlations to the seasonal efficiency were analysed for the following parameters: (i) increasing heat and work load, (ii) low overdimensioning, (iii) low domestic hot water demand, and (iv) high energy demand. Problems could be identified in test cases with low heat loads. In these cases boilers are often overdimensioned; sometimes installers did not care to perform heat load calculations or there was no suitable boiler model available.

Furthermore the results could not be further evaluated in respect to the climate. Unfortunately, on the one side the two South European partners could not provide metering results, on the other side Hungary and Austria show a quite similar climate: The numbers of heat degree days only differ slightly (between app. 2.800 and 3.400); for this reason no dependencies of the efficiency or other parameters on the weather resp. climate could be identified.

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