STATE OF THE ART IN RESEARCH on MEASURING and MODELLING DOMESTIC HEATING APPLIANCES in the EU

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ABSTRACT

During the last decades the creation of a single EU market has put in focus the measurement and testing difficulties in Europe. Despite the existence of CEN harmonised test standards, the results of the tests of central heating boilers are not reproducible enough and this is a barrier for the development and application of regulations and directives aiming at energy saving and CO_2 reduction.

The impact of central heating boilers in the EU is considerable. Domestic heating represents more that 20% of the total energy consumption and more than six million units are sold every year.

Grouped into a network, **LABNET**, laboratories have been organising pre- and co-normative research in order to solve the existing problems. With a strong involvement of the EU Commission, a number of actions have been carried out by the laboratories and have resulted in significant improvements.

INTRODUCTION

Until recently, measurement and testing was not considered an important problem. But during the last decade the EU situation has evolved very much. Domestic heating represents more than 20% of the total energy consumption world-wide and without accurate measurements it is difficult to set up regulations to improve the technology and thus reduce CO_2 emissions. Therefore, with a strong involvement of the EU Commission numerous actions have been carried out and have resulted in clear improvements.

In the EU, testing of appliances has been through several changes during the last 15 years. Not so long ago, the testing and the appliance certification were done at a national level, and at few locations in each country. The **measurement accuracy and the inter-laboratory reproducibility** were not seen as an issue. Moreover, the comparison of testing results was difficult because the testing requirements and conditions, fuel used etc. could differ from country to country. With the introduction of CEN standards, the comparison of test results from different laboratories became more straightforward and the laboratories started to investigate this question in the early 90's.

The problem appeared to be crucial with the introduction of the CE mark and the free circulation of goods in the EU. The new **boiler regulations** (EU Directives) in the mid-90's threw light on the measurement problems. Labelling systems showed to be inapplicable because of the poor reproducibility of efficiency measurement in the EU.

The reproducibility (R) is the value, below which the absolute difference between two single test results obtained with the same method on identical test material, under different conditions (different operators, different apparatus, different laboratories, and different time) may be expected to lie with a specified probability of 95% **(ISO 5725).** *In other words, the reproducibility gives an indication of the range of efficiency between the lowest and the highest value measured. Note: It is a range and not a ± value.*

THE CREATION OF LABNET

The creation of **LABNET**, a network of laboratories, was decided and the action carried out by the laboratories since has resulted in a number of improvements on many fronts thanks to a strong **co-normative and pre-normative** work supported by the EU Commission. LABNET has a website: http://labnet.dgc.dk/.

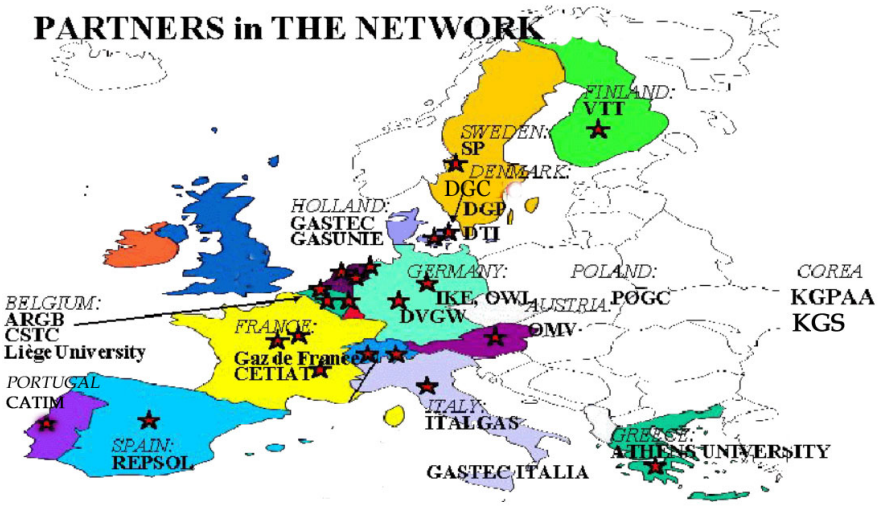

Figure 1 Partners in the LABNET network

The volume of work carried out until now by the network represents about 4 million Euro. Today, the 25 member laboratories have developed a high degree of concern about their uncertainties, and achieved considerable progress in the control of the measurement errors and uncertainties.

One of the results of the LABNET work is the creation new procedures that can help obtain a better reproducibility among the laboratories. Some aspects (e.g. **electricity consumption**) of appliances have become a growing concern among the consumers, so pre-normative efforts were required also for that purpose. LABNET has also extended its scope to modelling and especially for the calculation of **seasonal efficiency** to be used for consumer information and labelling.

TESTING AND MEASUREMENT IN THE EU

What is Tested Today?

The requirements to boilers and hot water appliances are basically **efficiency** and **emissions**. Recently, also **electric consumption** has been included and **noise** is also becoming an issue, especially after it was introduced in a EU directive (labelling). **Safety** is, of course, a very important issue, but there is no problem, as far as testing is concerned.

The main concerns today are **heating** and hot **water production**. Cooking is not outside the scope of the work of LABNET, but there are no directives regulating emissions or efficiency for cooking, and therefore the interest is much lower. Moreover, energy used for cooking in the EU is probably less that 1/20 of the energy used for heating and hot water production, therefore the lower priority.

The Information to Consumers - a New Need

When looking back in the history of measurement and testing we can see that the reasons behind the tests have changed through the years, and therefore it might be useful when discussing this issue to consider whether the present standards are still suitable for the purpose they were created for or supposed to be used for.

Twenty years ago, the standards were mainly created to guarantee the **safety** of the users. Also, **construction requirements** were introduced on the request of the manufacturers to somehow guarantee a minimum reliability of the appliance. **Efficiency** was introduced later when the concern about energy savings developed, and **emissions** followed when the environmental concerns developed, especially in Germany and Switzerland.

The introduction of the boiler directive and labelling directive also suddenly created a need for covering consumer **information** aspects and this is not covered by the EU standards (that are typically progressing slower than directives - therefore this gap).

Information is directed to the consumer concern and the information needed is therefore practical data, such as energy consumption or heating costs. Therefore, the standard values of nominal efficiency or even part load efficiency are not necessarily suitable for this purpose, as they are not reflecting the real energy consumption or annual efficiency at the consumer's place. One main obstacle is that standards are dedicated to the appliances alone, whereas the real performances of the appliance are also depending on the installation. Therefore, the boiler cannot be treated like the other white goods, and the concept of "installed appliance" was created in order to differentiate the boiler from other appliances.

There is, today, a gap between the standards and the directive: the standard describes the measurement of nominal efficiency at part or full load, and some directives relate to annual efficiency. Therefore, a tool is needed that can calculate the second from the first. Such tools do exist (e.g. BOILSIM), but it is necessary that the industry comes to an agreement whether to use the tool and how to use the tool.

Uncertainties and Standards

The standards on boilers are generally only indicating little on the accuracy of instruments to be used. This was useful as long as there was no better tool to help the laboratories, but today those indications have become obsolete. One of the points of the new approach is not to request a minimum accuracy for each measurement (as in the present standards), but to request a minimum overall accuracy (on efficiency or emission) with total freedom how to achieve this: it is up to each laboratory to set up its own and adapted strategy in order to fulfil the standards.

The multiplicity of standards having similar or different requirements is confusing the situation; therefore, it would probably be more effective to include in one document all needed information related to the measurement aspects that are common to several standards for boilers. This includes uncertainty.

In the EU, the control of the requirements on measurement accuracy is non-existing. This means that there is no guarantee that a laboratory measuring efficiency has the requested accuracy specified in the boiler standards. Most of the laboratories are accredited, but even this accreditation is not ensuring the guarantee either. In practice, most of the laboratories are making a rough uncertainty estimate that is generally optimistic.

All Round Robin Tests carried out up to now have shown that there was a gap between the results obtained and the accuracy claimed by the laboratories.

STATE OF THE ART OVERVIEW

Measurement of Efficiency Early Work

Already in 1993, the laboratories started to work on the efficiency measurements following the first Round Robin Test (or inter-comparison test) that showed very poor reproducibility among the laboratories. A project [1] was launched with the aim of investigating the error sources and improving the overall reproducibility. The work was organised in specific parts:

- **Stability Criteria**. A new method to make automatic detection of the boiler thermal stability before tests was developed and validated. This method is largely used today, especially in automatic smart test rigs.

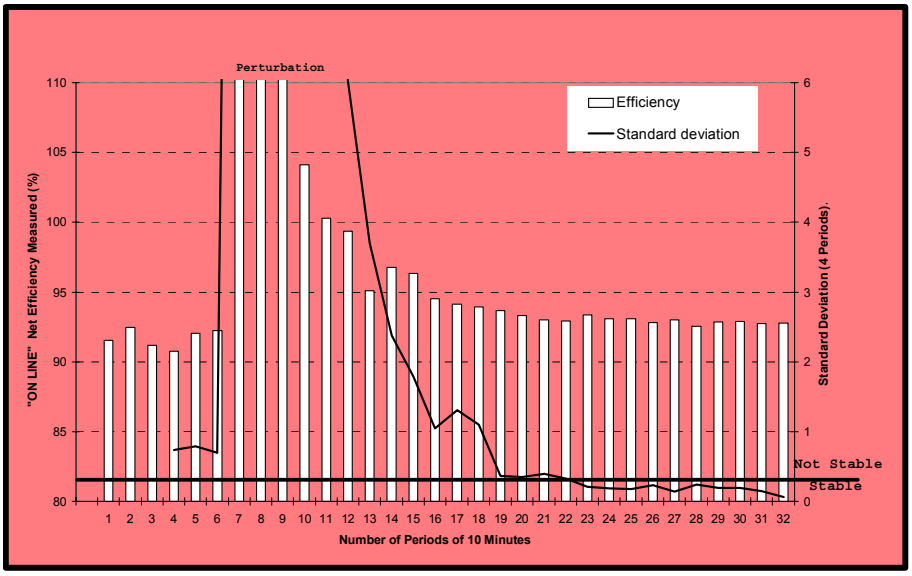

Figure 2 Detection of stability during the efficiency test. The efficiency is measured every 10 minutes and compared with the previous values. Specific stability algorithms conclude if the thermal stability is reached and if the efficiency value measured can be validated.

- **Influence of Ambient Conditions.** Models to correct the influence of ambient temperature and pressure have been developed in order to avoid expensive tests in rooms with controlled temperature.

- **Uncertainty Calculation.** A method was developed allowing to harmonise the way to calculate the uncertainty and to take into account all identified errors and uncertainties.

- **Heat Contribution of the Pump.** When the pump of the boiler is running during the tests, a certain amount of electric heat is transferred to the water. The method rather precisely calculates this amount of heat.

- **The Influence on Efficiency of the Calorific Value** has also been checked, as the tests in the EU can be made in most places with natural gas, the quality of which, however, is different. The calculations and the tests have proven that there is no measurable influence.

An important achievement of the work was the **GLP document** (Good Laboratory Practice). The document includes the procedures resulting from the experience of the European experts in measurement. New procedures resulting from the research programme

were also added. The application of the GLP has resulted in improved results, and today the inter-laboratory reproducibility for full load efficiency has improved from about **4.5% to about 3%.** For part load efficiency the differences between laboratories are still large despite improvements.

Inter-comparison Tests

The inter-laboratory reproducibility is measured by means of **inter-comparisons where** the same boiler is circulated to all the participating laboratories.

The very first test of this nature was organised 10 years ago and to the surprise of many participants it made clear that the discrepancies were much larger than expected. Looking at the detailed results, another observation was that **the actual uncertainties calculated by the laboratories could not explain such differences**.

This discovery has caused a number of speculations and discussions about the validity of the test and other explanations, but the later experiments (see below) and tests proved the fact that **most of laboratories are not having the good accuracy they think they do**.

But perhaps the most important result of the project was that the laboratories decided to continue to co-operate in order to further improve the measurement of efficiency on boilers and so, LABNET was created (1996).

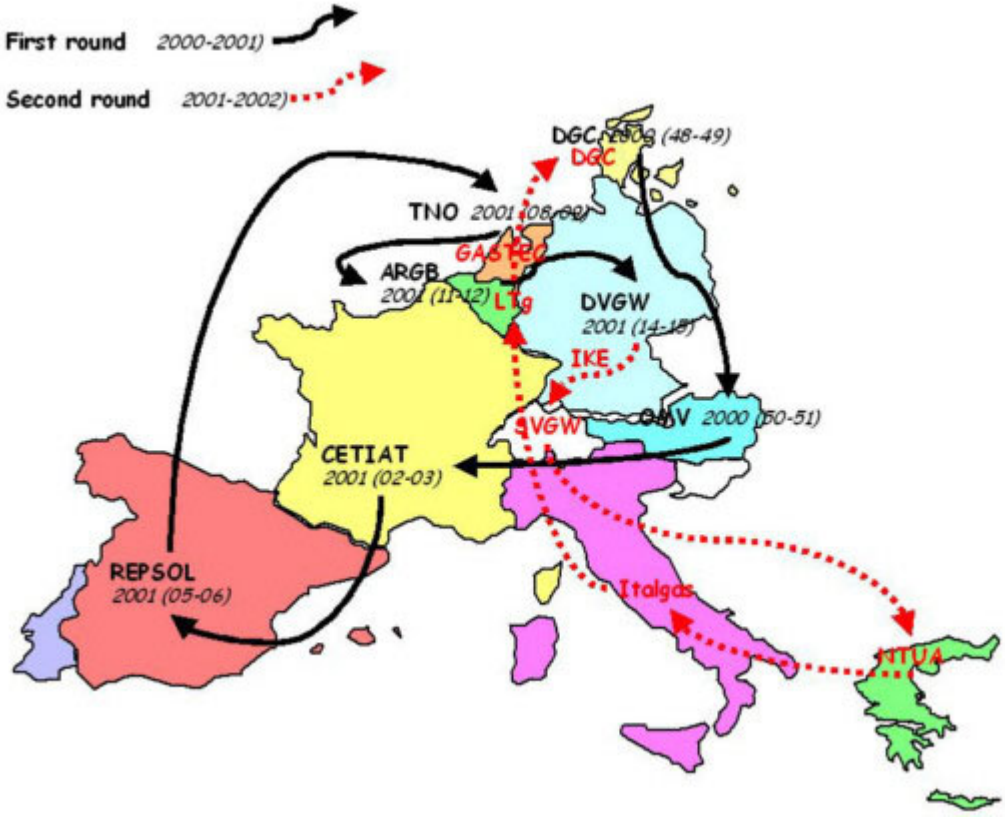

Figure 3 Example of inter-comparison test in the EU (2000-2002)

One of the questions remaining was how to further improve the reproducibility and especially at part load. We knew we had large differences, but did not know where exactly. Therefore, a new concept of inter-comparison was created with a test rig able to diagnose the laboratory measurement [2]. This rig was used by several laboratories (1997-2002).

Instead of sending a reference boiler alone, a complete test rig with integrated top quality measurement equipment was built and circulated together with the boiler. This makes it possible to identify exactly the reason of the deviation on efficiency measurement as the individual measurements needed for the efficiency determination (temperature, flow, pressure etc.) of the laboratory are compared directly and at the same time to the reference rig.

As already suspected, we discovered that only few laboratories have a precise idea of their own uncertainty of measurement and this was the largest source of the differences. The problem was that as long as a laboratory believes it has a good accuracy (and this is not the general case), there will be no progress in the overall inter-laboratory reproducibility.

One of the crucial problems for laboratories is to convince themselves that they do not have the high accuracy they believe they do.

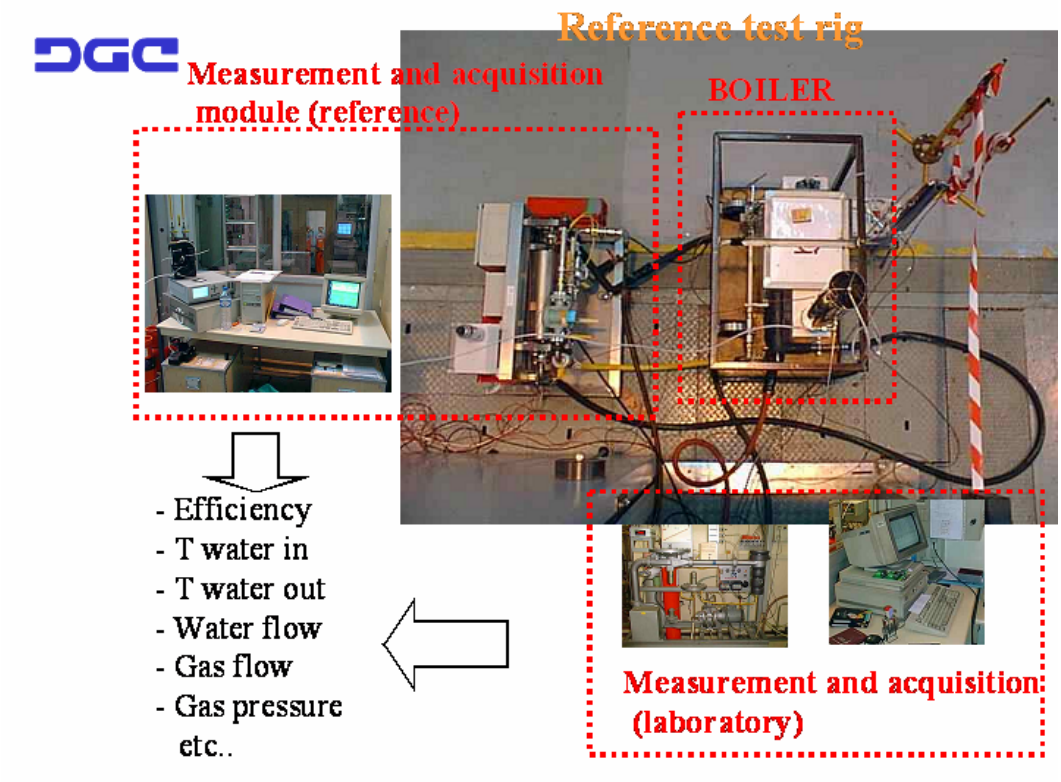

Figure 4 Principle of the inter-comparison with reference material (boiler and test rig)

NEW METHODS AND TOOLS

The direct follow-up action was to develop an **uncertainty diagnosis method** including the procedures/protocols to measure e.g. the drift of meters and other individual error sources (2000-2001). This was a very important step towards the overall improvement of the measurement situation. But it requires the effort of the laboratories to implement the method

and investigate the measurement appliances and method. At this stage, only few laboratories have implemented the method entirely. The overall situation of type testing business is not very favourable to investment and implementation of new procedures, but the method was used in a more recent inter-comparison (2001-2003) and the idea to use it is progressing.

In the same period, there has been an increasing interest for cheaper and more accurate methods. The so-called **indirect efficiency, later on called "loss-efficiency**", method (developed by a consortium of laboratories in LABNET [4]) has proved to be a simple, cheap and accurate way to determine the full load efficiency (2001-2003). The method can also be used together with models as BOILSIM (see below) in order to estimate the part load efficiency of the boilers, and in the long run it can replace the present direct determination.

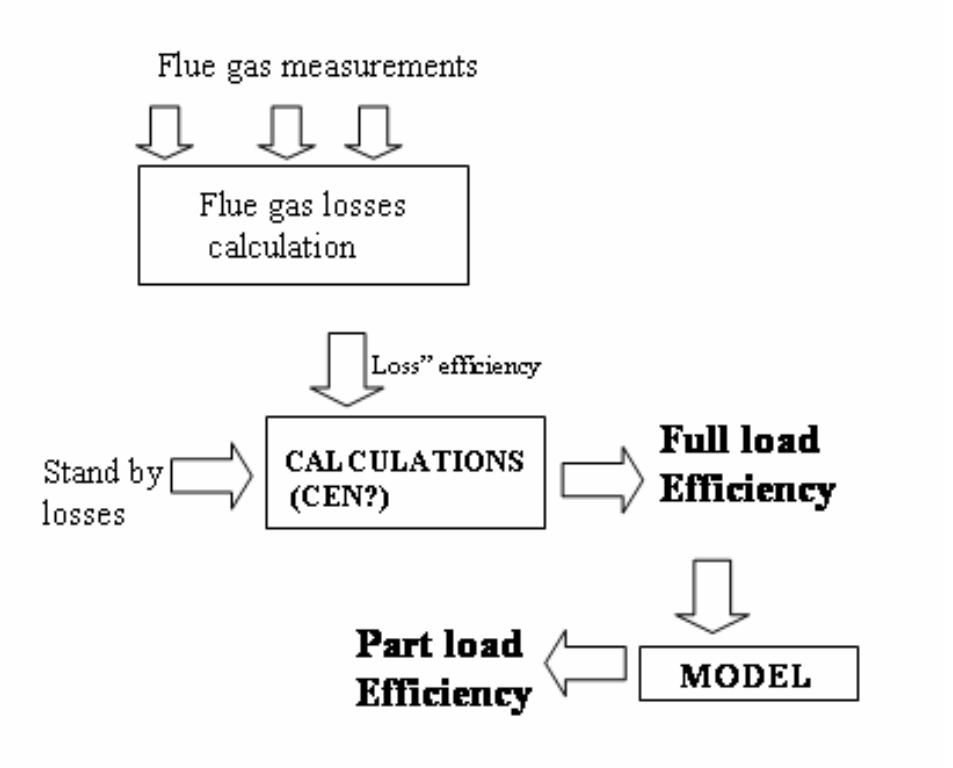

Figure 5 Principle of the loss efficiency method

For the newest boilers the method seems already to be as accurate as or more accurate than the former direct method. There is still room for accuracy improvement if the standby loss measurement and CO_2/O_2 determination can be done with a better accuracy.

Calculation of Part Load and Annual Efficiency. Replacing Measurement with Models.

Validated models as BOILSIM have already been used for several years by some laboratories (e.g. DGC) to calculate part load efficiency and so to save testing time obtaining results with equivalent accuracy to measurement accuracy. The part load model developed in BOILSIM has proven to bring results within the measurement accuracy, and more laboratories have in the recent past shown interest for using the method.

The BOILSIM method also applies to the determination of annual or seasonal efficiency of boilers: this is nothing more than the integration of several different part load efficiencies resulting from the different operating conditions of the boilers.

The annual efficiency is the information that is useful to the consumer. The boiler efficiency depends on the installation the house (heat demand) and the operation conditions. These can be calculated from data of the installation and climate with a model as BOILSIM.

Today, the BOILSIM model has been through several development phases [5], which we will not discuss here, but the method has been validated through numerous tests, especially in Denmark. The model has proven to be as accurate as measurements or even more in certain circumstances.

The applications of the method are therefore rather wide:

- Labelling of boilers.
- Information to the consumers.
- Education of installer.
- Etc.

BOILSIM, therefore, can be an important tool for the practical implementation of different EU directives related to CH boilers.

Using models instead of measurements for certification is rather revolutionary in the field of standardisation for domestic boilers, but there are other CEN committees and standards that have included the use of models in their procedures. The benefit of models is generally cost saving and more flexibility. Models would also be convenient for the application of EU standards on sanitary hot water as on the basis of the same test data they could enable the calculation of the tapping efficiency for different tapping pattern adapted to different situations or countries.

Hot Water Production

The hot water production is a topic that has been much debated during the last years. An EU labelling directive (92/72) expressly mentions hot water appliances under the scope of application and some studies in the past [6] have investigated how such labelling could be organised for the hot water appliances. In the same time, CEN has produced a standard. The tapping pattern program was subject to much discussion and controversy.

The accuracy of measurements is certainly an issue for the hot water appliances. However, there has never been an inter-comparison that has shown the real reproducibility of the laboratories (the first one is planned in 2005). The calculations done [6] indicate that the uncertainty is probably around 10% and maybe even more for the combi-boilers equipped with a water tank. The high uncertainties are linked to the dynamic test conditions. Especially the numerous small tappings are leading to errors during the transitional periods. This is one of the weak points of the present standard. Considering that the full load efficiency for heating under stable and constant conditions is causing difficulties, one can imagine that the hot water efficiency under dynamic conditions would bring a number of additional challenges.

Therefore, the utilisation of models based on simple and accurate measurements could be much more accurate and lead to more flexibility: any tapping pattern can be calculated

without any extra tests, which makes the choice or changes of tapping pattern easier, e.g. calculation of national or specific tapping patterns with the same original input test, where the parameters of the model are measured. The basis for such models already exists [5], but the validation of simple models and definition of the needed tests to make the model operational are still incomplete.

Also, an inter-comparison test would be useful both for getting an idea of the real reproducibility of the efficiency obtained with the present CEN standards and for checking the reproducibility of the measurement of the parameters needed for the model (tank standby loss, boiler heat constant etc.). This inter-comparison is presently organised in LABNET and will take place in 2005.

Emissions

The emissions also were the subject of a wide investigation [7] that led to a Good Laboratory Practice document (GLP). For the time being, the procedures have been implemented by different laboratories on a voluntary basis.

Influences such as the influence of the humidity on the NO_x emission were the object of investigations [8] and the results were implemented in the GLP [7], together with a large number of new procedures and requirements on the tests and measurements including the analysers, sampling etc.

The latest value of reproducibility available is from an inter-comparison test organised within the framework of the project (1996-98). The values obtained are in the range of 10 to 20%, but for emissions the reproducibility is much related to the level of emissions measured: the smaller the emission, the larger the value of reproducibility.

As the requirements in force in the EU are not too severe, the reproducibility is probably not seen as a major issue. This might change the day the emission limits are strengthened.

The actual situation in the EU is that part of the industry and laboratories considers the GLP on NO_x and CO too complicated. As a matter of fact, the full understanding and control of the parameters that influences the measurement accuracy require an expertise and time that is difficult to find for many laboratories as time is money! Furthermore, the analyser/measurement instrument characteristics are not always available, and laboratories are testing boilers and not testing measurement instruments!

Furthermore, for the time being nobody has resources to work further on an extended simplification of the document.

Therefore, an alliance with other sectors of industry with a far more intensive activity in measuring pollutants shall be considered. In the EU, a number of recent developments have been made in CEN [9], mainly by sectors of industry in charge of pollution control.

One possible smart way to organise the standardisation of emission measurement for boilers would be to use the recent and existing standardisation work made by the CEN/TC 264 and write from the GLP document a specific, but simplified document for the boilers.

As only little focus was given to emission until now (for boilers the focus is clearly on efficiency) there has be no real debate or preoccupation. Therefore the issue of NOX and CO measurement has been on standby for a while, but in the near future environmental questions will become more and more actual.

WHAT ACTION IS NEEDED NOW?

Remedy to the Existing Technical Weak Points

The action carried out in the past has not only improved the situation, but it has also shown where it needs further improvement.

Even if progress has been achieved on the **efficiency measurement,** continuous efforts are required to keep the quality and to improve it further. Implementing the existing tools, such as harmonised uncertainty, and make them more user-friendly is one of the most important actions. As seen, the loss efficiency method seems for the newest boilers already to be as accurate as or more accurate than the former direct method. Also the **standby loss** (despite being less important considering the final effect) seems to suffer from large uncertainties without any obvious reason. Moreover, the loss efficiency method shall be **validated** with further tests for fuel oil boilers and condensing gas boilers.

When the **hot water appliances** will be subject to labelling, we will encounter severe problems with the reproducibility. There is an urgent need to organise an RRT (on going) and to improve the actual methods so as to guarantee a minimum accuracy in the results. A wise way to achieve this would be to use models that would allow flexibility and accuracy.

To improve the information to consumers and installers there is a need for a large **EU boiler database** with efficiency test results, standby losses (basically BOILSIM parameters) and the development of an interactive tool on the Internet. This discussion is urgent as many national initiatives will make the organisation and harmonisation of such a system difficult.

For improved modelling of installed boilers the **start-stop frequency of the boiler** should be analysed. It depends on the boiler and installation characteristics, and the availability of a model would be very useful for the more accurate annual efficiency determination, as well as for annual emissions. Moreover, **the reliability** of boilers, which is an increasing concern, would also benefit from such a study.

About the Laboratories' Situation

The inter-comparison tests show that despite the efforts done there are still differences, and especially at part load. At the same time, the financial situation is difficult for many laboratories that have seen their testing activity decrease and, in some instances, even stop. In this context it is difficult to ask laboratories to invest in better instruments or heavier procedure. However, as the success of the network proves, the laboratories are interested in working together to improve the situation. Working together at common solutions is also the most effective and cheap way to achieve results.

One of the reasons that explain the general slow implementation of the new procedures is the lack of time: most of the laboratories have a workload that makes it impossible for them to take the time to study in detail documents or new method descriptions.

This means that laboratories have difficulties in implementing new procedures when they are complicated. Not because of lack of expertise, but because of lack of time needed to implement the procedures properly. For example, 30% of laboratories claim they have problems with assessing the parameters needed for the calculation of the method proposed for the harmonised uncertainty calculation method.

Simplification of the Procedures and Test Methods

Priority shall be given to simple, but accurate new procedures, such as the loss efficiency and now that the methods exist, an important work of promotion and implementation is needed. The simplification shall not harm the accuracy. More than ever there is a need for accurate measurements.

Harmonisation of Quality Assurance (Q/A)

There is a general demand for the organisation of Q/A at EU level as there seems to be large variations in the severity of assessment among the different laboratories. This means that the laboratories feel they are not treated on an equal basis. The organisation of the Q/A at EU level would also make the Q/A cheaper for the laboratories when sharing a number of Q/A procedures.

For example, the organisation of the calibration frequency by meter type (supported by a majority of the laboratories) is one idea towards the harmonisation of the quality control procedure.

Furthermore, it would be useful to have more insight on how the calibration institutes in the EU compare. There have been some doubts about the tolerance of calibration given by some calibration institutes. An inter-comparison test (same instrument calibrated by different institutes), would bring some light on this question. It would also highlight the importance of the tolerance by the calibration institute. It is of the utmost importance to have a correct figure for the tolerance of calibration, as this information is determinant in the evaluation of the overall uncertainty of measurement. It is also determinant for the choice of strategy chosen by the laboratory to improve the overall uncertainty. Wrong information on calibration tolerance can lead to a wrong and inefficient strategy. The same applies for data from the instrument manufacturers.

There is a gap between the information required for the detailed calculation of uncertainties and the data from the calibration institute, but the main data are the data from instrument manufacturers. Most of the technical information from the instrument manufacturers is not complete and one can also speculate about the validity of the data given. Therefore, initiatives such as an instrument database or a certification system for measurement instruments would be very favourable. The first one is a present ongoing activity in LABNET.

Instrument Database

In order to facilitate the use of the methods developed in LABNET (e.g. uncertainty calculation method) the development **of a measurement instrument database** is one of the projects that would help considerably. The laboratories will not need to evaluate themselves the instruments' characteristics: when the considered instrument is in the database, data will be available without further research or investigation, apart from the data that are specific to the given appliance and that should be covered by the calibration. Moreover, the data will be the same for all the laboratories and the value of uncertainty given would be comparable as calculated on the same basis (this is far from being the case today).

We have already introduced this concept of database in the existing tools, like the uncertainty calculation spreadsheet. Known characteristics of instruments have been gathered in order to elaborate statistics that are used for users with no information on their instruments and to calculate so-called "worst cases" to be used in case the real value is not known.

Inter-comparison Tests

Among the procedures that are widely used and accepted, the inter-comparison tests are here to stay. There is not only a high demand for the test, but also the national organisation in charge of accreditation is making those mandatory in several countries.

The Integration of the Results Achieved

Looking at the work already done, we can conclude that the most effective action would be the integration of the existing positive development (e.g. loss efficiency method) in the standards. The way to organise this is to be discussed with the industry and the standardisation organisations.

LABNET - an Instrument of Integration for New Member States

LABNET is a very important network for keeping the quality of testing at a high level in the EU and for solving the existing problems. LABNET can also help the **integration of new member states**: the new laboratories and notified bodies will at once get access to the information needed for the tests and measurements; they can participate in RRT and through direct contact between colleagues they can solve their problems and progress much more efficiently to learn the EU procedures and achieve the accuracy equivalent to that of the other laboratories.

CONCLUSION

The testing market has entered a crisis as a logical consequence of the CE marking. The **global reduction of the testing volume** has been resulting in a restructuring of many laboratories in a globally difficult context linked to the energy market liberalisation accompanied by a general reduction of the R&D efforts, also in the sector of testing and measuring. Under these conditions, it is very positive that members of the LABNET have still been willing to work together to achieve better tests and measurements. LABNET has in fact grown during the last years.

Discussion forums are created to facilitate the communication between the laboratories, standardisation organisations and the industry. Today, the laboratories are highly concerned about their uncertainties, and many of them have achieved considerable progress in the control of the measurement errors and uncertainties. Still, there is an important effort to be done for the implementation of the work in the standards or test procedures and still a number of technical challenges lies ahead.

The **enlargement of the EU** will bring new challenges for the uncontroversial application of the standards. The addition of new members who have not yet the experience of the procedures and standards makes a wide collaboration a priority for the integration and equal interpretation and application of EU standards and directives.

The LABNET network is also open to non EU members. Recently, two members from Asia joined and we hope others will, too. Measurement and testing issues are international and common issues and we would like to collaborate with other large gas countries like USA, China, Canada, Russia, Japan etc.

In the future, the introduction of new technologies, such as **micro CHP or fuel cells** and the development of **mixed energy systems** (e.g. gas, solar) will bring a number of new challenges for testing and measurement.

For further information you may look at the website: http://labnet.dgc.dk/.

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