Department for
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Heat meter accuracy testing

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Authors:

David Butler
Building Technology Group, BRE
Garston, Watford, Hertfordshire WD25 9XX
ButlerD@bre.co.uk

Alan Abela
Building Technology Group, BRE
Garston, Watford, Hertfordshire WD25 9XX
AbelaA@bre.co.uk

Chris Martin

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Executive summary

This report presents the findings from a research project to evaluate how accurate heat meters are when subject to installation and other errors, and to provide a robust evidence base to be able to assess errors. The work also investigated the factors that determine the optimal period between recalibration of installed heat meters.

Context

Heating accounts for nearly half of final energy consumption in the UK. The Government has committed to a financial incentive scheme to encourage the uptake of renewable heating. This is the Government's principal mechanism for driving the transition to the deployment of renewable and low carbon heat over the coming decades.

In order to build an evidence base for policy making, and to assist in the development of new and innovative heat technologies, DECC runs field trials to measure and monitor the in-situ performance of heat generating equipment. Heat meters are devices used to measure thermal energy. Accurate heat meter measurements are essential for effectively measuring the performance of heat generating technologies. Payments made under the Non-Domestic Renewable Heat Incentive Scheme are based upon heat meter readings, and hence meter accuracy has a direct impact on payments and value for (taxpayer) money. There is currently uncertainty regarding the accuracy of heat meters when subject to a variety of installation errors and how this accuracy may decrease over time, and published research in this field is limited. DECC have commissioned this research project to investigate various aspects of heat meter accuracy.

Scope

The overall purpose of this research is to evaluate how accurate heat meters are when subject to installation and other errors, and to provide a robust evidence base to be able to assess errors.

The essential objective is to arrive at appropriate metering specifications for measuring heat generated under both the Renewable Heat Incentive (RHI) scheme and DECC research projects.

Heat metering in the UK is relatively recent and is not particularly widespread, in comparison to other utility metering[1]. As the work progressed, the scope developed to include obtaining an

[1] There are 25 million households in the UK out of which a very small fraction might not have an electricity meter. Commercial establishments are also metered. Approximately half of these households have water meters. According to the Combined Heat and Power Association, 130,000 homes were connected to district heating networks (and might be expected to have heat meters) in 2012, and this figure was expected to double by 2017. There are approximately another 22,000 heat meters installed for the RHI.

understanding of the factors determining the optimal period between recalibration for installed heat meters.

This report presents the outcomes of this work.

Methodology

The starting point was an analysis of previous research carried out on heat metering accuracy, with a specific focus on installed heat meters rather than laboratory testing. This was synthesised with a review of relevant findings from on-going in-situ metering projects. The latter provided the main source of data for actual heat meter installation in the UK. The information gathered during this first phase of the research project was used to develop a laboratory test programme for specific heat meter types to quantify the impact of possible meter installation shortcomings. On the basis of the available data for heat meter installations, comprising a population of nearly 22,000 heat meters, it was agreed with DECC to test the following heat meter types: ultrasonic, vortex, and mechanical (rotary multi-jet). Additional research was carried out on recalibration periods and on meter accuracy over time, as well as investigating the different procedures in place in other EU states for testing and recalibration of installed heat meters.

Test programme

Ultrasonic meters account for nearly 70% of the non-domestic RHI meters installed and 34% of the domestic RHI meters installed[2]. On this basis it was agreed with DECC to test two different types of ultrasonic meter, together with one type of vortex meter and one type of mechanical meter. In all instances the brands of meters selected for testing represented the makes with the largest proportion of meters installed from the RHI database. The dimensions selected for testing (DN 25 and DN40) are considered representative of the non-domestic market on the basis of the nominal heat capacity of these meters when operating at typical commercial heating conditions. A total of eight new DN25 meters (four ultrasonic, two vortex and two mechanical) and four new DN40 meters (two ultrasonic and two vortex) were purchased for inclusion in the test program.

The scope of the test program is to obtain an understanding of the effects on accuracy when the heat meter installation does not fall within the parameters recommended by the manufacturer. The range of tests carried out can be broadly grouped into three categories:

a. Calibration tests. These consisted of tests where the meters were installed in accordance with the manufacturers' recommendations and tested against calibrated flow and temperature references.
b. Tests to investigate the effect of incorrect installation. These tests included individual installation errors such as incorrect orientation or incorrect location as well as combined installation errors.
c. Tests to replicate the effect of field conditions. Field conditions included but were not limited to transient operation, system dirt, and installation in actual systems.

Data on the potential deterioration in performance of heat meters with time is very limited. In order to draw some comparison between new and used meters, six used vortex meters removed from operational sites where they had been installed for approximately three years were also tested under the calibration test procedure.

[2] Data supplied by DECC from the RHI database and presented in main report.

Findings

The new meters were purchased in identical pairs and the calibration tests were used to establish that there was no significant variability between two meters of the same type and dimension. The tests actually demonstrated little variability between new meters of different types, but this could have been expected since all meters tested were classified by their respective manufacturers as compliant with the requirements of the MID Class 2 for heat meters.

The various tests carried out to investigate the effect of incorrect installation and to replicate the effect of field conditions highlighted different outcomes on the two independent components of energy measurement, namely flow measurement and temperature measurement. The results showed that flow measurement on new meters was particularly resilient to incorrect installation (an average flow measurement error over the four makes of DN25 heat meter at nominal flow rate over the complete range of tests of 2.74%) with the main exception being the effect of air entrainment on ultrasonic meters which ceased to register any measurements with the presence of air. Other significant errors were noted with combinations of air entrainment, incorrect orientation, and high flow rates for vortex meters, combination of air and proximity to pump for vortex meters, and proximity to bends for ultrasonic meters.

The measurement of temperature difference for all meter types tested was very reliable when the temperature sensors were inserted in the flow, whether in pockets or in 'Binder' type test points (these are self-sealing fittings that allow the sensor to be inserted directly into the fluid flow). The magnitude of the average error in energy measurement over this range of tests for the four makes of DN25 heat meter was 3%. Measurement of temperature difference was less accurate for strap-on temperature sensors whether these were the standard sensors or even in the case of specifically designed strap-on sensors, with an average error magnitude in energy measurement of 9% and even larger errors measured when the two temperature sensors were installed differently from each other (up to 60%).

An estimate of the overall impact of installation errors on heat metering accuracy across the DECC RHI has been made. Although some installation faults have been found to produce quite large errors in heat metering it is known, from audit visits, that they occur on only a relatively small number of sites. Monte Carlo analysis has been used to combine the results from the test program with statistics on the frequency of different types of installation errors from RHI heat metering audits. This revealed that over the entire available data sample, combining the errors according to the weighting of the sampled population, the overall uncertainty of metering is between -5.9 and 2.8%, with a 95% confidence interval.

Additional research was carried out on recalibration periods and procedures in other countries in the EU. The scope was to develop a metering specification for both the RHI and DECC research projects, to obtain a better understanding of the financial implications of meter inaccuracy, and to determine the optimal recalibration period for installed meters

The tests in an old house heating system, whilst still on-going, have showed significantly different susceptibility to dirt between the meters. There was also a marked difference between the two ultrasonic heat meters. One ultrasonic heat meter displayed a large over reading of energy and flow (over 30% for first five days of test when the system also had circulating air) whilst the other ultrasonic meter showed a relatively low susceptibility (a steady state error of -5%). The other heat meters including the other ultrasonic meter, the rotary meter and the reference electromagnetic flow meter initially showed much less sensitivity to dirt. However, later on in the test the vortex and rotary meters showed a gradual continuous decline in accuracy whereas the accuracy of the two ultrasonic meters stabilised.

Conclusions

It was found that the various meter types tested are generally robust even when not installed in accordance with the manufacturers' recommendations. Specifically the flow sensor generally performed within the MID class tolerance even when not installed in compliance with the manufacturers' recommendations. The temperature sensor pair only performed within the MID class tolerance when installed in the fluid flow. The calculator performed within the MID class tolerance as long as it was correctly configured for the specific installation.

Therefore, the main criterion to ensure that the accuracy of installed meters remains within the range of the MID class is the type and installation method of the temperature sensors. Temperature sensors must be installed in the fluid flow (using pockets or 'Binder' type points) for accurate energy measurement.

Recommendations

Metering for DECC research projects requires a higher level of accuracy than the RHI and apart from the installation method for temperature sensors mentioned above, the main factors to be considered are the resolution of the meter and the method of data collection. These need to be matched to the predicted output of the system to be metered. Whilst the installation effects on heat meter accuracy are generally within the MID class parameters, in order to achieve improved accuracy for DECC research projects, it is recommended that wherever possible, in situ calibration be carried out.

The optimal recalibration period for installed meters is difficult to determine, although it appears that a number of EU states have done so arbitrarily. Some countries have taken a more logical approach through a statistical sampling procedure every five or six years. This provides the flexibility to extend the recalibration period for a batch depending on the outcomes of the sample testing.

This research has continued to develop on previous work carried out by DECC on renewable heating and heat measurement. Whilst the results of the laboratory test program generally indicate heat meter energy measurement can achieve a high degree of accuracy and reliability, even when installation varies from the manufacturers' recommendation, the test program itself is inherently limited in terms of both number of meters tested and length of testing period and further work is recommended to investigate the possibility of deterioration of heat meter accuracy with time.

Introduction

A heat meter is a device which measures thermal energy provided by a heat source such as a boiler or heat pump, or delivered to a heat sink such as a central heating system or hot water cylinder, by measuring the flow rate of the heat transfer fluid and the temperature (ΔT) between the outflow and return legs of the system. Heat meters consist of a flow sensor, a pair of temperature sensors, and a calculator. Typical applications of heat meters are the measurement of heat delivered to consumers by district heating systems, or the measurement of the heat output of say a heat pump, or the cooling output from a chiller.

In 2012, almost half (47%) of final energy consumption and over three quarters of non-transport energy use in the UK was for heating uses. In the 2009 Renewable Energy Strategy, the Government committed to the Renewable Heat Incentive (RHI), a financial incentive scheme to encourage uptake of renewable heating among householders, communities, and businesses. The RHI is the Government's principal mechanism for driving the transition to the deployment of renewable and low carbon heat over the coming decades.

In order to build an evidence base for policy making, and to assist in the development of new and innovative heat technologies, DECC runs field trials to measure and monitor the in-situ performance of heat generating equipment. Accurate heat meter measurements are essential for effectively measuring the performance of heat generating technologies. There is currently uncertainty regarding the accuracy of heat meters when subject to a variety of installation errors and how this accuracy may decrease over time, and published research in this field is limited.

The overall purpose of this research is to evaluate how accurate heat meters are when subject to installation and other errors, and to provide a robust evidence base to be able to assess errors.

The essential objective is to arrive at an appropriate metering specification for measuring heat generated under the domestic/non-domestic Renewable Heat Incentive (RHI) as well as for DECC research projects.

The methodology consists of analysis of previous work carried out on heat metering, a review of relevant findings from on-going in-situ metering projects, and laboratory testing of specific heat meters to quantify the impact of possible meter installation shortcomings. Additional research was carried out on recalibration periods and on meter accuracy over time, as well as investigating the different procedures in place in other EU states for testing and recalibration of installed heat meters.

This report presents the outcomes of this work, which consisted of both an analysis of available information on heat meter errors (Task 1), and a laboratory test program for different meter types and installation configurations (Task 2).

The information available for Task 1 was defined to include, but not be limited to, the following sources:

- A previous study that was commissioned by DECC and carried out by AECOM (AECOM, 2013) doing some initial work on heat meter errors.

- Two heat pump monitoring programs carried out by DECC and interim results of both projects made available to the contractor for gap analysis purposes
    - The domestic field trial focused on metering 700 heat pumps from the Renewable Heat Premium Payment (RHPP) scheme (Wickens, 2014).
    - Field trial monitoring of 24 non-domestic heat pumps is currently being undertaken

- RHI scheme data (commercially confidential), which includes:
    - Breakdown of the types of meters being used in the RHI
    - Different types of flow measurement devices and products
    - Breakdown of failures in heat meters
    - Non-compliances on the RHI as a result of heat meters

On the basis of the above sources, as well as other available information and knowledge of the industry, the scope of Task 1 is an analysis highlighting the following points:

What are the gaps in testing on the potential errors and consequences of heat meter errors?

- Are there any further sources of measurement errors DECC should be aware of?
- Which installation errors are likely to have the biggest impact on measurement error, how frequently do they occur, and how uncertain is the current evidence base on the magnitude of these errors?
- Further testing of errors that should be undertaken for a robust assessment.
- The data about in-situ meter errors that has been obtained from these studies
- Any conclusions that can be drawn as a result of these findings
    - Breakdown of the types of meters being used in the RHI
    - Different types of flow measurement devices and products
    - Breakdown of failures in heat meters
    - Non-compliances on the RHI as a result of heat meters

The principle outcome of this analysis is a recommendation for a cost-effective series of heat meter tests to meet the objective set out above and as a basis for Task 2.

Task 2 consisted of the execution of the agreed heat meter test program and the analysis of the results. The scope of Task 2 was the testing of different types of meters to answer the research questions outlined above. The minimum requirements were the repeat testing on two meters of the same type, testing a minimum of four to six different error types, and the testing of combinations of errors. The test program developed in Task 1 included these requirements together with additional tests using a purpose built rig, a heat pump test rig and test houses to calculate in-situ measurement errors. The test results were analysed to obtain an understanding of the type of installation errors or conditions that would have a significant effect on heat meter accuracy. This analysis together with the research carried out as part of Task 1, and additional research requested by DECC provided the basis for the definition of the conditions for accurate heat metering in *Conclusions and Recommendations*.

It should be emphasised that the contents of this report include various references to commercially sensitive data provided by DECC in relation to the RHI heat metering exercise. References to this data and the findings arising from it cannot be published in any format without specific authorisation by DECC.

Background

Relevant Standards

The Measuring Instruments Directive (2004/22/EC) (MID) is a directive by the European Union, which seeks to harmonize many aspects of metrology across all member states of the EU. Its most prominent tenet is that all kinds of meters which receive a MID approval may be used in all countries across the EU where legal metrological control is prescribed.

BS EN 1434:2007 Parts 1 to 6 is the UK implementation of EN 1434:2007 Parts 1 to 6. EN 1434 is harmonised to the MID and defines general requirements, constructional requirements, data exchange and interfaces, pattern approval tests, initial verification tests, and installation, commissioning, operational monitoring and maintenance of heat meters.

The International Organisation of Legal Metrology (OIML) has also published international recommendations on heat meters, consisting of documents OIML-R75 Parts 1 and 2 covering general requirements, type approval tests and initial verification tests. The requirements of OIML-R75 are the same as the specifications of EN 1434.

Annex MI-004 of the MID defines a heat meter as an instrument designed to measure the heat which, in a heat exchange circuit, is given up by a liquid called the heat-conveying liquid. The directive further specifies that a heat meter can be either a complete instrument, or a combined instrument consisting of the sub-assemblies consisting of the flow sensor, the temperature sensor pair, and the calculator.

Heat meters are not subject to legal control in the UK. However the RHI regulations define the minimum standards that heat meters must meet in order for measurement of the amount of renewable heat that is eligible for RHI payments. The non-domestic RHI scheme regulations stipulate that heat metering must comply with the specific requirements listed in Annex MI-004 to the MID and fall within accuracy class 2 as defined in the Directive whilst the domestic RHI scheme regulations stipulate that metering should meet the requirements for accuracy class 3.

Flow Sensors

A velocity-type meter measures the velocity of flow through a meter of a known internal capacity. The speed of the flow can then be converted into volume of flow to determine the usage. There are several types of meters that measure water flow velocity, including jet meters (single-jet and multi-jet), turbine meters and electromagnetic meters.

Multi-jet meters

Multi-jet meters are very accurate in small sizes (up to about 50mm pipe diameter) and are commonly used as water meters for residential and small commercial users. Multi-jet meters use multiple ports surrounding an internal chamber to create multiple jets of water against an impeller, whose rotation speed depends on the velocity of water flow. Multi-jets are very accurate at low flow rates, but there are no large size meters since they do not have the straight-through flow path needed for the high flow rates used in large pipe diameters. Multi-jet meters generally have an internal strainer element that can protect the jet ports from getting clogged.

Turbine meters

Turbine meters are less accurate than jet meters at low flow rates, but the measuring element does not occupy or severely restrict the entire path of flow. The flow direction is generally straight through the meter, allowing for higher flow rates and less pressure loss than displacement-type meters. They are the meter of choice for large commercial users, fire protection and as master meters for the water distribution system. Strainers are generally required to be installed in front of the meter to protect the measuring element from gravel or other debris that could enter the water distribution system. Turbine meters are generally available for 1-½" to 12" or higher pipe sizes. They are accurate in normal working conditions but are greatly affected by the flow profile and fluid conditions.

Electromagnetic meters

Electromagnetic meters use Faraday's Law of Electromagnetic Induction to determine the flow of liquid in a pipe. In a magnetic flow meter, a magnetic field is generated and channeled into the liquid flowing through the pipe. Following Faraday's Law, flow of a conductive liquid through the magnetic field will cause a voltage signal to be sensed by electrodes located on the flow tube walls. When the fluid moves faster, more voltage is generated. Faraday's Law states that the voltage generated is proportional to the movement of the flowing liquid. The electronic transmitter processes the voltage signal to determine liquid flow.

This flow meter does not obstruct flow, so it can be applied to clean, sanitary, dirty, corrosive and abrasive liquids. Electromagnetic flow meters can be applied to the flow of liquids that are conductive, so hydrocarbons and gases cannot be measured with this technology due to their non-conductive nature and gaseous state respectively.

Electromagnetic flow meters do not require much upstream and downstream straight run so they can be installed in relatively short meter runs.

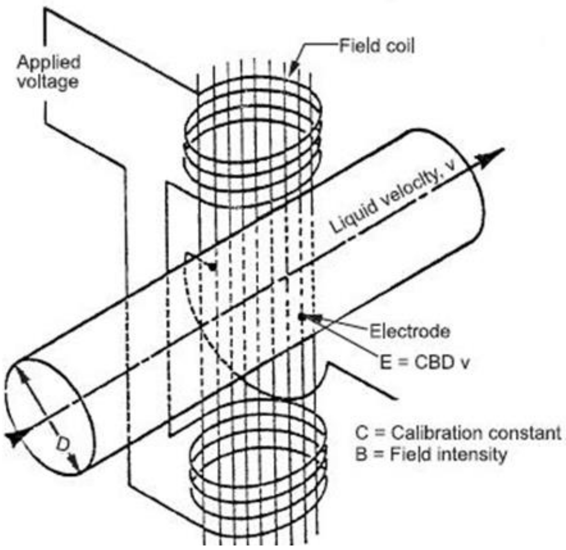


Figure 1: Operating principle of electromagnetic flow measurement

Ultrasonic meters

Ultrasonic flow measurement using the transit-time differential method is now one of the most universally applied flow metering processes. Flow is generally measured using the bidirectional ultrasonic technique based on the transit time method, with proven long-term stability and accuracy. Two ultrasonic transducers are used to send the sound signal both against and with the flow direction. The ultrasonic signal travelling with the flow direction reaches the opposite transducer first. The time difference between the two signals can be converted to a flow velocity and thus a volume. Ultrasonic meters are non-invasive and have no moving parts. Long unimpeded inlet runs are needed for accurate measurement.

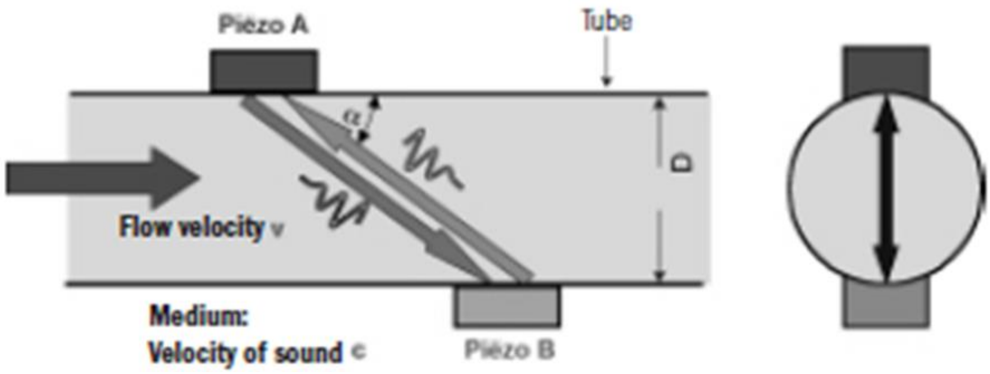


Figure 2: Operating principle of ultrasonic flow measurement

Vortex meters

Vortex flow meters, also known as vortex shedding flow meters or oscillatory flow meters, measure the vibrations of the downstream vortexes caused by a barrier placed in a moving stream. The vibrating frequency of vortex shedding can then be related to the velocity of flow.

When a fluid flows steadily over an isolated cylindrical solid barrier above a limiting value of the Reynolds number (typically 90), vortices are shed on the downstream side. The vortices trail behind the cylinder in two rolls, alternatively from the top or the bottom of the cylinder. This vortex trail is call the von Karman vortex street or Karman street after von Karman's 1912 mathematical description of the phenomenon.

The Karman street has two significant influences on the principle of operation of vortex flow meters:

- The frequency of vortex shedding is definite and is related to the Reynolds number (flow velocity, viscosity of fluid, and the diameter of the cylinder).
- The frequency of vortex shedding is the same as the vibrating frequency of the cylinder induced by the flow.

If the density and viscosity of the fluid are known and the diameter of the cylinder is given, the frequency measured at the cylinder can be used to represent the flow velocity. Low flow rates present a problem for vortex meters because they generate vortexes irregularly under low flow conditions.

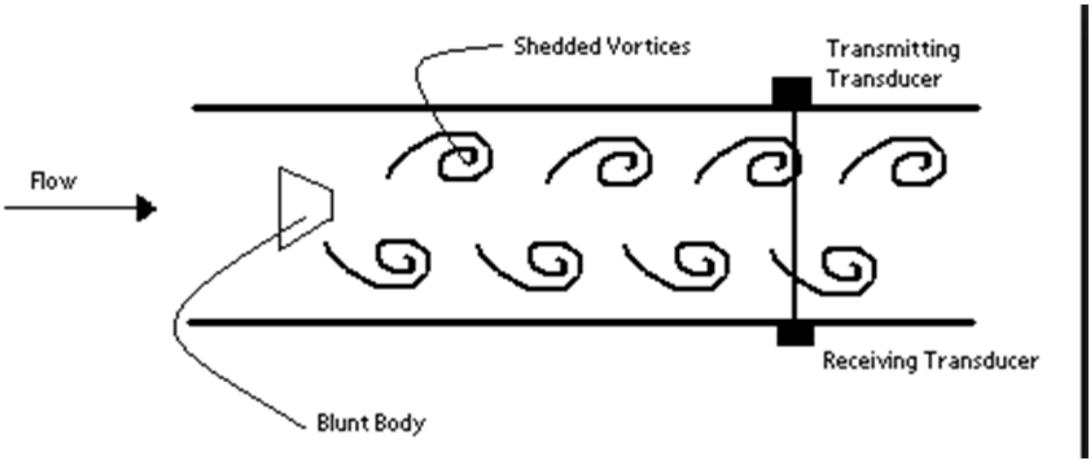


Figure 3: Operating principle of vortex flow measurement

Temperature sensors

Resistance thermometers, also called resistance temperature detectors (RTDs), are sensors used to measure temperature by correlating the resistance of the RTD element with temperature. Most RTD elements consist of a length of fine coiled wire wrapped around a ceramic or glass core. The element is usually quite fragile, so it is often placed inside a sheathed probe to protect it. The RTD element is made from a pure material, typically platinum, nickel or copper. The material has a predictable change in resistance as the temperature changes and it is this predictable change that is used to determine temperature.

Platinum resistance thermometers (PRTs) offer excellent accuracy over a wide temperature range (from –200 to +850 °C). Standard sensors are available from many manufacturers with various accuracy specifications and numerous packaging options to suit most applications. Unlike thermocouples, it is not necessary to use special cables to connect to the sensor. The heat meters in the RHI domestic and non-domestic databases analysed by BRE, and also the heat meters tested as part of BRE's test programme, used PT100 or PT500 type PRT temperature sensors.

The principle of operation is to measure the resistance of a platinum element. The most common type (PT100) has a resistance of 100 ohms at 0 °C and 138.4 ohms at 100 °C.

Figure 4: Typical platinum resistance temperature sensor built into steel tube suitable for installation in pipes.

Market Data

Market data for heat meters is limited and different and sometimes contradictory figures are published by different sources.

The installed base of heat meters in Europe in 2008 stood at around 10 million units (Centre for Strategy & Evaluation Services, 2010), with annual demand at around 800,000 units[3]. The market for heat meters is relatively diverse in the EU with Germany, Poland, Sweden, Denmark and Finland representing over 70% of the European market. The European market is dominated by Kamstrup (around 47% of the 10 million installed meters).

Other large manufacturers are Diehl, Landis & Gyr, and Itron (Centre for Strategy & Evaluation Services, 2010).

The German market claims a total of 12 million installed heat meters in 2006 (Rose, 2006) with a manufacturing capability of just under one million units per year. This value contradicts the previously stated value of 10 million units in 2008. Since the 10 million value was based on work undertaken for Lot VI for the Interim Evaluation of the Measuring Instruments Directive, this may be the more accurate value.

Investigation of HIUs

Apart from heat metering in connection with renewable heat, another significant market for heat metering is district heating. In this market heat metering is normally installed in the Heat/Hydraulic Interface Units (HIUs) installed between the network and the end user. The selection and the way that heat meters are installed within HIUs provides additional information to inform the testing, including calming sections, orientation, installation position and dirt.

The majority of individual HIU suppliers in the UK market and who were listed in the HVAC Product Finder and Supplier Directory (http://www.hvindex.com/product-names/1032) were contacted. Most of these suppliers claim to sell around 1,000 units per annum, making a total estimated UK market of approximately 25,000-30,000 units per year. The installed base of heat meters in HIUs therefore currently exceeds the number of heat meters installed under the RHI.

Metering arrangements have been investigated for 26 manufacturers of HIUs.

Specific details of heat meters included with HIUs were available from specifications that are readily available for approximately half of these manufacturers/suppliers.

The preferred measuring principle for the flow meter was ultrasonic, which was the only available option for ten manufacturers/suppliers. Two manufacturers offer to provide HIUs with either ultrasonic or mechanical meters. Generally the temperature sensors are PT100, and occasionally PT500.

Four manufacturers provide HIUs with no meters, but with a spool piece (typically 100mm or 130mm in length which are typical of heat meters for connection to ¾” and 1” pipework respectively) so that meters can be fitted if separately supplied.

Details about heat meters were not available within HIU specifications for ten manufacturers.

A representative sample of HIU manufacturers/suppliers have been contacted to establish their reasons for selecting specific meters and to understand their views on heat meters. Manufacturers have said that heat meters are fitted to the majority (~95%) of HIUs supplied in the UK.

[3] This is not confirmed by Kamstrup who declare 2.2 million ultrasonic meters sold up to 2013.

In general, their choice of heat meter supplier is based on a combination of space requirements and historic relationships but this was influenced by the introduction of metering within the RHI (when some HIU suppliers adapted their units to provide MID Class 2 meters).

Most HIU manufacturers are adaptable and can accommodate alternative meters which are supplied by the district heating provider for some large district heating projects, or where clients (typically designers or installers) have had problems (no details provided) with the default meter provided with the HIU.

HIU manufacturers reported no specific requirements in relation to the orientation of the heat meter and that there was no requirement for external straight sections of pipe ('calming sections') upstream of the heat meter. They considered that there was no problem with installing the heat meters in either the return or flow section, and also claim that the heat meters are insensitive to dirt.

No HIU manufacturers had tested the accuracy of meters after they have been fitted to HIUs (manufacturers rely on the calibration certificates provided by the meter suppliers).

Heat meter considerations

Orientation: Several suppliers stated that the heat meter was capable of orientation in horizontal or vertical pipework. Others did not provide details of any particular requirements with respect to orientation. None stated that there were specific requirements for orientation.

Glycol: Two meters were not suitable for use in systems with a mixture of water/glycol.

Calming sections: Only one meter required a straight pipework section (35mm) upstream of the meter. Two of the Siemens meters required the temperature probe of the heat meter to be ten diameters downstream of the 'T' for temperature probes fitted on common returns on heating/DHW circuits.

Pipework connection: details of locations for the heat meter location were not specified for approximately half of the heat meters. Where statements about the position were provided these typically described how meters could be fitted to either the flow or return section. Only one heat meter stated that it was for installation in return pipework only.

Layout within HIUs

Figure 5 shows a typical layout of a HIU and the location of the heat meter (reproduced with kind permission from Altecnic Ltd).

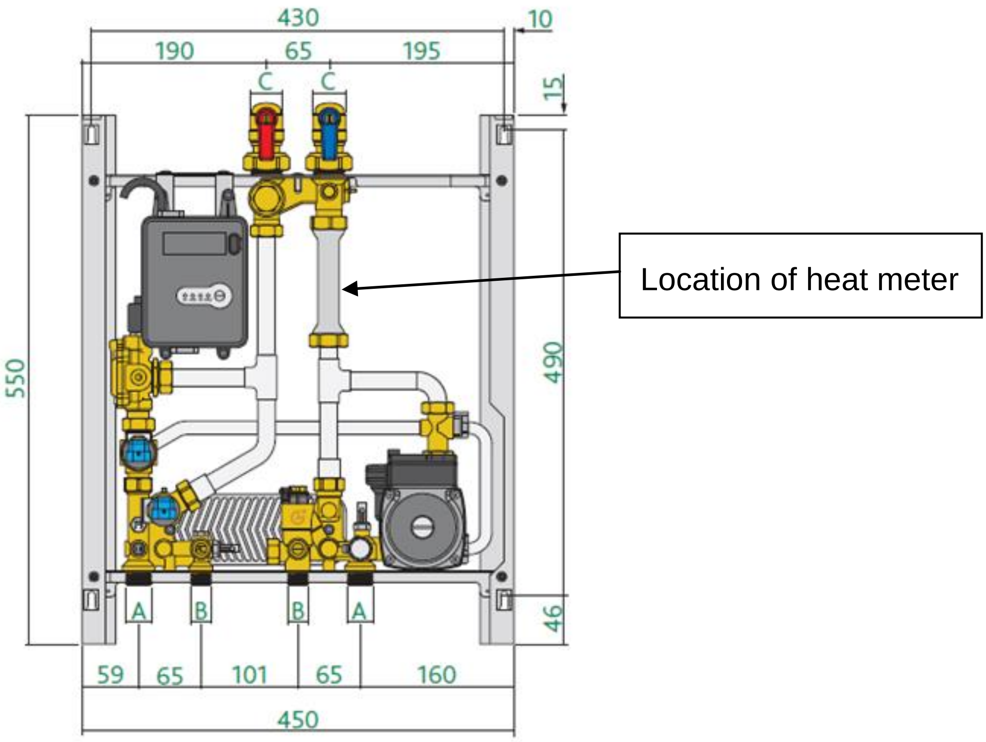


Figure 5: Typical HIU layout (reproduced with kind permission of Altecnic Ltd)

Heat Meter Products installed on HIUs

The following table (Table 1) lists a selection of heat meter manufacturers, along with manufacturers which incorporate these meters within HIUs. Table 2 identifies specific heat meter products which feature within HIU specifications.

Heat Meter Manufacturer	HIU manufacturer
Danfoss	Danfoss, SAV
Kamstrup	Altecnic
Itron	ELCO, Ideal, Altecnic
Sontex	ELCO
Sharky	Altecnic, Vital Energi, Herz
Siemens	Potterton, EnerG
Rossweiner	Pegler
Maddelena	SAV
Multical	ELCO
Lanten	ELCO
Landis & Gyr	Altecnic, EnerG
Ista	Altecnic

Table 1: Selection of heat meter manufacturers and which HIU manufacturers incorporate them

Manufacturer	Heat Meter	Suitable with glycol	Calming section required	Sensitivity to Dirt	Flow meter in Flow/ Return
Danfoss	Sonometer 1100	?	?	Y	?
Ista	Ultego III	N	?	?	?
Itron	CF Ultra Maxx	?	?	?	?
Itron	CF Echo II	?	?	?	F/R
Itron	Integral Maxx	?	?	N	?
Kamstrup	Multical 402	?	?	?	F/R
Landis & Gyr	T230	?	?	Y	?
Maddelena	microCLIMA	?	?	?	?
Rossweiner	HeatPLus	?	?	?	F/R
Rossweiner	HeatSonic	?	?	?	F/R
Diehl	Sharky 775	?	?	Y	?
Siemens	Megatron TED 5332	?	Y	?	F/R
Siemens	UH50	N	N	Y	R
Siemens	2WR6	?	N	Y	F/R

Table 2: Heat meter products featured in HIU specifications

The following table (Table 3) is a list of HIU manufacturers who supply products in the UK.

Alfa Laval	Herz Valves UK Ltd
Altecnic Ltd	Ideal
Baxi	Johnson and Starley
Danfoss	KVM
Dutypoint	MHG Heating Ltd
ELCO UK	Mibec
Elson	Pegler Yorkshire
EnerG	Potterton / Baxi
Evinox	SAV Systems UK Ltd
Ferroli Ltd	Stokvis Energy Systems
Frese	Vital Energi
Giacomini	Wilson Energy
Hartons	Zero carbon heating

Table 3: HIU manufacturers

Conclusions

Whilst in other European countries district heating schemes are widespread, and constitute the major proportion of the heat metering market, this is not necessarily the case in the UK since district heating is far less common. Heat meters in HIUs are used for billing purposes by district heating suppliers. Within such schemes any inaccuracies in metering are catered for along with system inefficiencies and transmission losses and included in determining the chargeable rates for the service. The requirements for meter accuracy are catered for by HIU manufacturers by ensuring that the meters fitted meet the industry accuracy requirements and that the installation is carried out in accordance with the meter manufacturers' instructions.

Analysis of information on heat meter accuracy

Heat meter accuracy

Accurate heat meter measurements are essential for effectively measuring the performance of heat generating technologies. Under the non-domestic RHI scheme (and in some circumstances in the domestic scheme) payment is made on the basis of metered heat. In the domestic RHI additional payments are offered to participants who take out a Metering and Monitoring Service Package. In the non-domestic scheme heat meters are required to be MID class 2 compliant, to be properly calibrated prior to use, including for any water/ethylene glycol mixtures, and to be properly installed in accordance with the manufacturer's instructions. In the domestic scheme heat meters are required to be MID class 3 compliant, properly installed, calibrated and in good working order. DECC is also undertaking a number of heating system field trials in which the accuracy of heat meters is critical.

EN1434 is the European Norm which specifies the requirements including initial verification tests for heat meters, and is harmonised to the MID. The sections of the standard which are most relevant to this discussion describe the accuracy which the flow meter, temperature sensors and calculator must achieve, and the information which a manufacturer should deliver as part of the product documentation. The required accuracy for each application type, residential (Class 3) or commercial/light industrial (Class 2), is defined in Directive 2004/22/EC of the European Parliament and of the Council of 31 March 2004 on measuring instruments (MID).

Heat meter accuracy is commonly specified using the class notation. The standard defines accuracy of instruments in terms of Class 1, 2 or 3, with Class 1 being the most accurate. These classes are referred to in the Directive. The pair of temperature sensors does not have an accuracy class, and neither does the calculator, so it is only the flow sensor which has the associated accuracy. The allowable Maximum Permissible Error (MPE) for temperature sensors is the same no matter what the accuracy class of the complete assembly is.

The accuracy required of the flow meter defines which Class is to be attributed to the complete metering system. For a Class 1 meter this is:

$$E_i = \pm (1 + 0.01\ q_p/q) \text{ but not more than } \pm 3.5\%$$

where:

E_i is the uncertainty in flow measurement expressed as a percentage;

q_p is the highest flow rate at which the meter can function continuously;

q is the actual operating flow rate.

For a Class 2 meter it is:

$$E_i = \pm (2 + 0.02\ q_p/q) \text{ but not more than } \pm 5\%$$

For a Class 3 meter this is relaxed to:

$$Ei = \pm (3 + 0.05\ qp/q) \text{ but not more than } \pm 5\%$$

To this must be added the uncertainties due to the measurement of temperature difference and also any uncertainties introduced by the calculator. These are treated differently to the flow meter requirements, in that they do not depend on class. For the temperature sensors they are:

$$Et = \pm (0.5 + 3\Delta\theta min/\Delta\theta)$$

where:

Et is the uncertainty in temperature difference measurement expressed as a percentage;

$\Delta\theta min$ is the minimum temperature difference for which the system is rated, and;

$\Delta\theta$ is the actual operating temperature difference.

For the calculator the corresponding equation is:

$$Ec = \pm (0.5 + \Delta\theta min/\Delta\theta)$$

where:

Ec is the uncertainty contributed by the calculator expressed as a percentage;

Finally, the standard requires that to determine the overall error, the absolute values of these errors must be combined as an arithmetic sum. These definitions have the effect that expected accuracy is dependent on actual operating conditions, particularly when operating at low flows, or low temperature drops.

EN1434 also requires that the heat meter manufacturer provides installation instructions defining a wide range of properties. The ones most relevant to this discussion are the permissible flow meter orientations, requirements for straight lengths of pipe required upstream and/or downstream of the meter, and the pressure drop across the meter at maximum flow. These can affect the accuracy of the heat meter when installed. High pressure drop increases the pump energy consumption and if the pump cannot compensate for the higher pressure drop the water flow rate may decrease below the design requirements. This may cause a reduction in the system heating capacity and a reduction in the energy efficiency of the heating appliance, especially if this is a heat pump.

The process of achieving MID accreditation is defined in Directive 2004/22/EC of the European Parliament and of the Council of 31 March 2004 on measuring instruments. EN1434 has been mandated by the European Commission to provide a means of conforming to the Essential Requirements of Directive 2004/22/EC. For this purpose compliance with all normative clauses in the whole of EN1434 (parts 1 to 5) is required (stated in *EN1434-1:2007 Annex ZA (informative), Relationship between this European Standard and the Essential Requirements of EU Directive 2004/22/EC, MID*). Therefore throughout this report where the requirements of EN1434 are stated these are also required to conform with the MID.

Review of existing literature on other potential sources of error

A literature survey was carried out on the testing, calibration, and sources of error encountered in both heat and flow metering. This commenced with the data sources indicated in the terms of reference of this project and was extended to include other published studies where these could be identified.

In 2012 DECC commissioned AECOM to report on the likely sources of error in their heat metering. The resulting report described the following possible sources of additional errors (AECOM, 2013):

- Gas entrainment
- Incorrect configuration for working fluid eg using glycol solution in a system where meter has been setup for water
- Flow meter installed in wrong orientation
- Upstream flow perturbations (this is described as meter downstream of fittings in the report)
- Flow meter mounted in flow rather than return, and not appropriately reconfigured

In the main body of the report water quality, in particular the presence of dirt, was also identified as a potential source of errors.

The Energy Saving Trust (EST) monitored 83 heat pumps in residential properties across Great Britain from April 2009 to April 2010. Some problems occurred during the installation of heat metering equipment – incorrect positioning of meters being the most common fault – even when the contractors had prior experience of installing monitoring equipment. Six sites were removed from the trials for this reason, and instruments were replaced on a further five sites (Dunbabin, Charlick, & Green, 2013).

Bohm (2013) identified that whilst heat meters are calibrated according to international standards, during calibration in a laboratory, flow and supply and return temperatures are maintained at constant values. In real life, both flow and temperatures vary dynamically during a draw off of domestic hot water, especially for single family houses. Tests at the SP Technical Research Institute of Sweden documented measurement errors up to 30% for some heat meters due to long integration intervals of the heat meter.

The Korea Research Institute of Standards and Science carried out tests on a total of 24 heat flow meters. The types of flow meter were turbine, electromagnetic, and ultrasonic, with diameters from 50 to 150mm. The flow meters were tested for accuracy and durability according to the International Organisation of Metrology R75-2 heat meter testing method. They were also tested for installation position (0°,90°,180°,270°) and vibration effects in the laboratory. The turbine meters showed deviations between -2% and 1% over the range of flows tested whilst the electromagnetic and ultrasonic meters were not affected by the rotation angle (vortex type meters were not included in this work). Field tests were carried out as well. The main finding from the field test was that in March (spring) when the heat flow rate starts to decrease, the electromagnetic flow meters showed a substantial negative deviation compared with the other types. This was attributed to the low flow rate caused by intermittent heating and the reduced use of hot water. The deviation of the flow reading of the electromagnetic flow meters in July was between -30 and -65%. The turbine and ultrasonic flow meters had deviations of less than ±2.5% for the field test period (Jan to Jul) (Choi, Yoon, Kim, & Choi, 2011).

In 2014 the Energy Monitoring Company (EMC) produced a document identifying additional sources of error which might have contributed to the heat metering used in the RHPP heat pump monitoring project (Martin, 2014). These were:

- Mounting of flow and return temperature sensors on the outside of pipework, rather than in the pockets supplied by the manufacturer
- Matching of the flow and return temperature sensors (to minimise temperature difference measurement errors), particularly significant at the low temperature differences often seen in well-designed heat pump systems. This should already be

included in the EN1343 or MID specification of the meter, and is not considered further here;

- The influence of the flow meter on the performance of the system being monitored;
- The effect of disturbances to the flow being measured due to upstream plumbing such as bends;
- Air bubbles within the system working fluid;
- The effect of dirt and other particles within the fluid;
- The position within the system where the flow meter is mounted (flow or return pipework);
- The use of working fluids other than water (i.e. antifreeze mixtures in various, possibly uncertain, proportions);
- The heat meter data sampling interval, which particularly affects performance over very short run-offs.

The EMC report was reviewed by three technical auditors appointed by DECC, and their responses are summarised below. Within the terms of reference of the review were two questions that are relevant to this study, namely:

1. Do you know of any other possible sources of measurement error when using this type of heat meter in this type of application?
2. If so, do you have any details of what the additional measurement errors associated with those sources might be?

The responses to these questions are summarised hereunder.

Graham Energy Management identified the fact that even when a flow meter is incorrectly mounted in the wrong direction, it still might give a reading. This had already been observed on the RHPP project (Hughes, 2014).

Grontmij drew attention to the fact that mounting heat meter sensors in pipework close to a storage tank might introduce significant errors due to conduction from the tank to the sensor. Another point highlighted was whether mounting a flow meter in close proximity to a pump could cause further errors. Partially blocked strainers where also identified as another form of potential upstream flow disturbance (Grontmij, 2014).

Ofgem listed as additional concerns the impact of discrepancy between fixing methods on flow and return temperature probes resulting in differing thermal contact/response, as well as ambient conditions having a different impact between the temperature sensor pair. Concerns were raised about the effect of flow meter orientation, and whether the issue of instrument stability over time had been addressed (Ofgem, 2014).

Table 4 summarises the previous research reviewed in this report. The literature review highlighted the fact that most research has been carried out on the performance of heat meters in laboratory conditions, and little information is available on their actual performance in the field. In particular, Bohm (2013) and Choi et al (2011) identified the possible sources of error related to the dynamic characteristics of typical heating and hot water systems. Understandably, these situations are difficult to reproduce in laboratory conditions. The review also demonstrates that most research has been carried out on the flow components of heat meters, and limited information is available on the effect of different methods of temperature sensor installation. Here again, the work carried out on the effects of different methods temperature sensor installation relates to steady state conditions and does not consider the dynamic characteristics of typical heating and hot water systems.

	AECOM	EST	Bohm (2013)	Choi et al (2011)	EMC (2014)	Grontmij (2014)	Ofgem (2014)
Gas or air entrainment	X				X		
Use of system working fluids other than water	X				X		
Incorrect flow meter orientation	X						
Upstream flow perturbations	X						
Mounting in flow rather than return	X				X		
Dirt in system fluid	X				X		
Incorrect positioning of meters		X					
Response of meters to real life dynamic conditions, particularly for battery operated meters with longer sampling intervals			X				
Response of meters to real life intermittent conditions				X			
The use of strap on temperature sensors					X		
The use of unmatched temperature sensors					X		
Impact of meter on flow being measured					X		
Excessive sampling intervals					X		
Temperature sensors installed close to storage tanks						X	

	AECOM	EST	Bohm (2013)	Choi et al (2011)	EMC (2014)	Grontmij (2014)	Ofgem (2014)
Flow meter installed close to pump						X	
Discrepancy in fixing of temperature sensors							X

Table 4: Summary of previous research on heat meters highlighted in literature review[4]

Analysis of current level of understanding of sources of error

In this section we summarise the current understanding of each of the possible error sources identified above. In view of the current level of knowledge, and the likely magnitude of any errors we then determine whether further laboratory investigation is justified. For clarity, the errors are categorised under the three headings of flow measurement, temperature measurement and heat calculation.

Flow measurement errors

Incorrect flow meter orientation

Inappropriate flow meter orientation can have a number of unwanted effects:

- basic accuracy may be adversely affected;
- reliability may be compromised; and
- long term calibration stability may suffer.

Basic accuracy is most likely to be affected in meters with significant mechanical components, as incorrect orientation changes the friction on moving parts. Arregui et al (2005) tested turbine meters for metering domestic water mounted at 45º to the correct position. As expected, errors were most significant at low flows and above 8% of the nominal flow rate the errors became negligible. At 1.5% of the nominal flow rate the errors ranged from -2.9 to +32.2%. In most heat metering applications it is unlikely for the system to operate at such low flow rates for any considerable time, and hence these values should not be representative of the errors which could be expected in practice.

The AECOM report describes tests on each of the three types of flow meter (turbine, ultrasonic, vortex) tested. All meters were tested in three positions, regardless of the manufacturers' instructions about orientation. The errors caused by incorrect orientation were low for both the turbine meter (around 2%) and the ultrasonic meter (around 1%). In the case of the vortex meter the errors were again within 2% with the meter facing vertically upwards or horizontally, but increased to around 4% with the meter facing downwards. The manufacture does not recommend installation with the meter facing downwards as it encourages any dirt in the system to collect in the oscillator chamber. The meter was subsequently re-tested in the correct orientation and the calibration found to have changed by approximately 2%, which suggests that this may indeed have occurred.

[4] The Arregui studies are on domestic cold water meters and are included in the literature review since no other information is available, but they are not relevant to the table.

Orientation may affect reliability for some meter types. When turbine meters are mounted face down this increases the possibility of water leaking through into the display area where the electronics that transmit a signal to the heat meter calculator are generally housed. These meters are often not suitable for mounting in vertical pipe runs. The installation instructions for one example of a vortex meter state that it should not be mounted face downwards, to avoid the possibility of dirt accumulating in the fluid oscillator body, or face upwards, since this encourages the accumulation of air.

Finally for meters with moving mechanical parts, an incorrect mounting orientation may result in unexpected wear on bearings, resulting in a long term change in calibration constant, and loss of accuracy over time.

EN1434 requires that manufacturers supply information about permissible flow meter orientations in their product data sheet. However, on site there may be situations in which these requirements cannot be achieved, such as, for example, when only a vertical pipe run is available in which to mount a meter which is only recommended for horizontal installation.

To conclude, a number of tests have been carried out by AECOM and Arregui, and these indicate that orientation induced measurement errors depend on the meter type and flow rate. These tests are to be repeated so as to be able to use data for cumulative error estimation. Heat meter orientation is known to increase the susceptibility of meters to other factors, in particular air and dirt, but this interdependency has not been previously tested. It is important to understand and quantify the sensitivity so that the effect on the accuracy of heat meters in the field can be predicted.

Upstream flow perturbations

Many flow meters must be installed so that there is a significant run of straight pipework before the location of the flow meter, and also, but to a lesser extent after the flow meter. This is to allow the straight pipe run to smooth out or eliminate ‘swirl’ in which may be introduced by valves, temperature sensor wells, pumps and changes in direction. Where it is not possible to install a straight length of pipework, flow straighteners, often consisting of a length of honeycomb, can also be used. Another reason for requiring a straight pipe run is to ensure that the velocity profile across the flow is fully developed, since most flow meters are measuring velocity which is then converted to the volumetric flow rate.

The sensitivity of a flow meter to swirl or unusual velocity profiles depends on the measurement principle. A meter which uses an axial turbine mounted directly in the flow is likely to be sensitive to swirl whilst one which uses a jet to direct the flow at a turbine or Pelton wheel will show a much reduced sensitivity. Meters which make single or multiple point velocity measurements in the flow rely on knowing the shape of the velocity profile to infer the total flow from these results.

The AECOM report presents a range of measurement results for a clamp on ultrasonic meter supplied by Sira[5], where the impact of introducing single and double bends, gate valves, reducers and expanders is examined. With the relevant obstruction five pipe diameters upstream of the flow meter the impact is found to range from -0.6% to -7.9%. In relation to the velocity profile effect on the performance of Woltman (turbine) meters the effect of gate valves upstream is examined and found to be insignificant (Palau, Arregui, Palau, & Espert, 2004).

Arregui (2005) looked at the impact of partially blocked strainers and concluded that this was not significant for turbine meters. Random blockages cause changes in calibration from -0.8% to +1.7%. A systematic blockage around the edge of the strainer (simulated by inserting a

[5] Clamp-on meters are not generally used for permanent metring installations but for temporary metering. In the case of clamp-on metering accuracy may also be affected by the installation method and pipe materials.

circular rubber washer) caused errors ranging from -1.4% to +4.8% for four out of the five meters tested, and 16.2% for the fifth.

The test in which two heat meters with differently mounted temperature sensors were compared, was also used to make a preliminary assessment of the impact of entry conditions. Inevitably, there was a different pipework arrangement at the inlet of the two meters installed for that test. Over a series of highly dynamic tests, the meters reported flows within 0.2% of each other. This shows that in this particular configuration these changes do not cause a significant difference in flow reading for the particular meter under test.

EN1434 requires that the flow meter manufacturer specify the necessary straight pipe runs required upstream and downstream to avoid these effects. Practical considerations mean that such guidance is not always followed, and it is important that the implications of this are well understood.

The tests described mostly relate to a single type of meter. The short field test described covered only one type of meter in one pipework configuration. There exists a high likelihood of this source of measurement error in site installations. A more comprehensive set of tests is required here, especially to establish sensitivity to the level of flow perturbation and the effect of deviations from the manufacturer's recommended installation. These test results can be used for cumulative error estimation. This testing is to be carried out by comparison – i.e. one meter installed immediately adjacent to the disturbance with a second meter installed correctly. Where significant errors are noted additional tests with varying distance between meter and disturbance were carried out to establish the sensitivity.

In conclusion this error has a high likelihood in practice but only partial testing has been carried out by AECOM and Arregui, and the Arregui tests were undertaken with a limited (single) range of meter types. A more comprehensive range of tests is to be undertaken, especially to establish the sensitivity of both small and large deviations from manufacturer's recommendations, and also with errors in combination.

Gas or air entrainment

Entrained gas occurs in heating system loops due either to dissolved gas being released from the working fluid, or to gas being produced as a corrosion product. The latter effect should be greatly reduced if appropriate inhibitors are used. Air can also be present in systems due to either incomplete 'air bleeding' following installation or subsequent opening up of a system for repair, or from being drawn into a system through leaks in parts of the systems operating at sub-atmospheric pressure. Inwards air leaks may sometimes occur at the suction (inlet) side of a pump or through a faulty automatic air bleed valve (see report section *Proximity to pumps*), although there is little experimental data on this aspect. The AECOM report describes anecdotal reports that gas entrainment can produce errors of ±30 to 50%, but without reference to flow meter type. AECOM conducted a limited number of laboratory tests, which indicated that behaviour was highly dependent on meter type:

- a turbine meter showed little sensitivity to entrained gas;
- an ultrasonic meter stopped working altogether, displaying an error code;
- a vortex meter showed a small sensitivity which, as the amount of entrained gas was increased, eventually caused its error to move outside of its Class 2 specification.

It is clear from these preliminary results that this effect can be significant, and that there are gaps in the current knowledge. Entrained air is possibly the most common reasons for deviation from the design condition in water flow systems and its effects are significant to the performance of the system not just to the metering. It is therefore proposed that it should be included in the forthcoming laboratory tests. Tests were carried out with realistic values of entrained air (between 0.1 and 0.67% depending on water flow rates).

In conclusion entrained air is a very common fault in heating systems and would therefore be expected to be present in conjunction with other installation errors. The effect of air entrainment on heat meter accuracy has not been fully investigated, either on its own or in combination with other installation errors. More comprehensive testing was therefore to be undertaken on a range of heat meter types and in conjunction with a range of other installation errors.

Dirt in system fluid

As with gas entrainment, there is only limited information available about the impact of dirt on flow meter calibration. The AECOM study (2013) again reports anecdotal evidence, that dirt can cause errors of the order of 10 to 15%.

Arregui et al (2005) investigated the issue of lime scale for turbine meters and mentions a specific turbine meter where lime scale deposits caused a consistent error of 25%. Not reported is the fact that severe limescale can result in loose sediment forming over time.

With electromagnetic flow meters one specific type of dirt which is known to create significant problems is magnetite. Deposition of magnetite affects the calibration of an electromagnetic meter (always negative deviations), and severe deposits may result in the electrodes of the flow meter being short circuited, and the meter failing altogether.

There is no fixed schedule for the settling of a magnetite layer. In one particular case measuring errors of up to 90% were found within a week, while in other plants this took more than a year. Typically it takes two to three months for a homogeneous magnetite layer to settle (Prseworski & Sukovic, 2000). This may be the reason that, whilst they are routinely used in calibration laboratories, there are very few heat meters which use this method of measurement.

Limescale and magnetite are conditions which appear over time and cannot be replicated in short term laboratory tests and are therefore excluded from the test programme.

In conclusion dirt is a very common fault in heating systems but its effect is very difficult to investigate in a laboratory environment and therefore there is very little information on its effect on heat meter accuracy or reliability.

Proximity to pumps

Pumps represent a unique form of flow disturbance. As well as distorting the velocity profile in a pipe and introducing turbulence and swirl they can introduce pulsations into the flow. In addition to this, the points immediately before and after a pump are likely to be minimum and maximum system pressure areas respectively. Low pressures may cause the formation of small air bubbles which may also compromise flow meter accuracy. At the same time specific site conditions may mean that the most convenient location to install the heat meter is adjacent to the pump.

Some manufacturers state that a heat meter should not be installed on the suction side of a pump whereas other manufacturers do not mention this aspect. For example, the installation instructions for the Itron CF Echo (ultrasonic) does not mention proximity to pumps, whereas the installation instructions for the Kamstrup Multical 402 (ultrasonic) states that the flow sensor should not be located at the suction side of a pump. The installation instructions for the Sontex Superstatic 440 (vortex) specifies minimum static pressures in order to prevent cavitation. The risk of cavitation is related to flow rate and static pressure and is most likely to occur near the suction side of a pump. Cavitation may affect the accuracy of most flow measuring devices and may be actually physically harmful including vibration, shock and materials erosion.

There is a lack of experimental evidence on the significance of these effects in heat metering systems, and for this reasons a sequence of tests is planned to explore them.

In conclusion the effect of a heat meter close to a pump is likely to have an effect on accuracy, especially depending which side of the pump the heat meter is located and whether there is entrained air or not. Manufacturers appear to provide different guidance on this effect, even for the same type of flow meter. There is a lack of experimental evidence and therefore the test program investigated the effect of mounting a range of heat meter types (including ultrasonic heat meters from two different manufacturers) before and after the pump and with and without air entrainment.

Mounting in flow rather than return

It is necessary to know flow meter operating temperature, since the properties of the fluid being measured vary with temperature. In heat metering applications this temperature is usually obtained from the flow or return sensors which are installed for the heat energy calculation.

It is normal practice in heat metering to mount the flow meter in the return circuit. The return circuit is always at a lower temperature than the flow circuit, and in some systems the difference may be considerable. Installing flow meter on the lower temperature circuit extends the life of the components. In some heat meters the return temperature sensor is integrated within the flow meter, and so this is the only mounting configuration possible. Other meters are supplied with separate flow and return sensors, and so the flow meter can be mounted on either side of the heat distribution system. In this case it is necessary to define the operating temperature of the meter for correct flow measurement. Most calculator modules can be configured to use the correct temperature but alternatively a small correction can subsequently be applied to the data (in the case of monitoring field trials).

Well designed heat pump systems should operate with relatively small temperature differences (of the order of 5°C) and so the correction is particularly small in this application, typically less than 1%. In the case of boilers the temperature difference is higher, and the AECOM report calculates that for some meters the correction may be up to 5%. However, the calculation of the effect is straightforward, and a number of manufacturers publish a correction chart.

In conclusion, since the impact of incorrectly installing the flow meter in the flow circuit rather than in the return circuit can be readily calculated from basic principles, this installation error is not included in the proposed testing program.

Impact of meter on flow being measured

A flow meter generally has a pressure drop across it and hence installation of the flow meter can itself reduce the flow through the circuit. Strictly speaking this is not a ‘measurement error’ as the meter reads the actual flow correctly. However, the introduction of the meter alters the operating conditions of the system. In the case of a heat pump installation, this flow reduction could result in a small performance reduction, as lower flows imply higher delivery temperatures and reduced thermodynamic efficiency.

The most direct way of assessing the magnitude of the effect is to compare the flow or even the actual performance of systems with and without a flow meter installed. An alternative method proposed by EMC proceeds as follows:

- using data from the system with flow meter installed, determine the flow rate;
- use the flow meter manufacturer’s data to evaluate the pressure drop across the meter at this flow. EN1434 requires that manufacturers make available the pressure drop across the meter at maximum flow. In practice most publish a curve giving the loss as a function of flow rate;
- using curves from the pump manufacturer determine the total pressure that the pump is providing. This is the total system pressure drop with the flow meter in place;

- from these two results find what the overall system pressure drop would be without the pressure drop across the flow meter;
- again using the pump performance curve, determine what the increased flow would be without the flow meter in place;
- finally, using data from the heat pump manufacturer, or a calculation from first principles, determine the likely impact on system performance.

An example calculation, for a real system, indicated that installing one particular brand of vortex flow meter could cause a reduction in flow of as much as 12%, and that this could in turn have result in a 1.5% reduction in heat pump performance.

The EMC report also draws on the results of a field test between meters. In this test, described in more detail in the following section, in which a second flow meter was installed on a monitored system, data is available from the original flow meter immediately before and after the installation of the second meter. The original system flow rate is approximately 20 l/min and comparing the flow rates before and after reveals that there is no detectable decrease in operating flow rate due to the addition of the second meter. This implies that the sample calculation above is an extremely pessimistic example.

In conclusion it is acknowledged that the installation of a heat meter will have some impact on the flow being measured. However, since the impact will always be known (since the flow rate is directly measured by the heat meter), and the magnitude of this impact can be anticipated by calculation this particular installation error was not investigated in the current test programme. However, the resistance to flow (pressure drop) of each of the range of heat meter types in the test programme was measured and reported so that the expected impact on flow rate and pump sizing can be determined and reported in the final test report.

Temperature measurement errors

Mounting sensors by strapping to the outside of the pipe

The installation method recommended by most heat meter manufacturers for the flow and return temperature sensors is to mount these in the fluid flow. This is generally accomplished by plumbing in brass pockets, and fitting the sensors into these pockets. This approach has the advantages that the trades doing the plumbing and installing the heat meter can work independently, and also that sensors can subsequently be changed without having to drain down the system.

When retrofitting heat metering it can sometimes be difficult or impossible to insert temperature probes into the flow. The most common problem is lack of space, although if isolating valves have been left out at the installation stage there may also be situations in which it is not feasible to drain down parts of the system. In such circumstances the only way of measuring flow and return temperatures may be to use sensors which are strapped to the outside of the pipework.

The National Measurement Office (Bruce, 2014) examined the issue of whether it was likely to be feasible for strap on sensors to meet the MID class 2 accuracy requirements and concluded that it would be very difficult for a strap-on mounting system to meet the required error levels. In addition to this, other concerns were raised as to how such sensors could be sealed against tampering and the possibility of vulnerability to changes in local ambient conditions. Ofgem (17 October 2014) indicated that the National Measurement Office confirmed that to demonstrate compliance with the MID (and RHI requirements) a manufacturer would need to undertake the appropriate conformity assessment procedure(s). These conformity assessment activities need to be conducted by, or under the supervision of, a Notified Body such as NMO (or an equivalent in another member state).

Situations in which it has been necessary to use strap on sensors arose in the RHPP domestic monitoring exercise, and have subsequently also arisen in the monitoring of commercial installations.

To determine the best mounting method, and ascertain the likely impact on uncertainties, a set of laboratory tests was carried out by the EMC on differently mounted sensors (Martin, Empirical tests of alternative methods of mounting heat meter temperature sensors, 2012) . The tests focused on the effect of errors occurring under dynamic conditions. Using the results the likely errors which could be introduced into heat measurements by using strapped on sensors were estimated.

The team carrying out the monitoring of commercial heat pumps went through a similar process. In contrast to the EMC trials these concentrated on the impact of strap on mounting on steady state measurement errors (Hughes, 2014).

In the RHPP monitoring project, one installer was sufficiently interested in the performance of taped-on temperature sensors to implement a simple field test. He had already installed correctly pocketed sensors on a heat meter in his own house. He subsequently installed a second heat meter, with taped sensors. With guidance from EMC he interfaced this meter to spare channels on his data collection equipment. The data collected from both meters could then be analysed. This test, which confirmed the results of the analysis described above, is described in full in the report (Martin, 2012). Table 5 below shows the results obtained, and provides a comparison between the corresponding analytical and numerical results and the field tests.

	Calculation method		
	Analytical	Numerical model	Field test
Short pulse (cycling	-7%	-6%	-6%
Long pulse	-3%	-3%	-4%

Table 5: Errors in heat measurement due to strapped-on temperature sensors (in one installation)

It is clear from the results in both reports that the use of strap on sensors can yield significant additional errors, and there is clearly a need for more experimental work to supplement that already carried out by Martin and Hughes.

In conclusion this error may in practice be quite common especially where heat meters have been installed in an existing system. There is a lot of concern about the acceptability of externally mounted temperature sensors since preliminary testing has shown relatively large errors are possible and this method of sensor installation increases the potential for gaming / tampering. Therefore a comprehensive and systematic range of tests was undertaken.

Poor or missing insulation

In order to measure the temperature accurately, it is necessary to ensure that the probes register the fluid temperature, and are not influenced by the temperature of the surroundings. Lack of insulation, poor insulation (loose), or failure to insulate both probes to the same standard can introduce considerable errors in the temperature difference evaluated by the calculator.

The Graham Engineering report (Hughes, 2014) on sensors attached externally to pipework gives some information on this. This focused on the effect of missing insulation on externally mounted (strap-on) sensors. Errors of up to 1.1C were noted when no insulation was installed, but these were reduced to 0.17C by the application of 19mm of insulation.

The impact of missing insulation on pocketed sensors has not been investigated. It should be less than for externally mounted sensors, but may still be significant. Missing or damaged insulation has been seen in the field with pocketed sensors where it affected one sensor and not the other and therefore created the risk of more significant errors.

In conclusion preliminary work has shown that the effect of poor or missing insulation is likely to cause very large errors with externally mounted sensors and there is also anecdotal evidence that it may also affect pocketed sensors. However, little previous testing has been undertaken and some information is anecdotal. Therefore a range of tests was undertaken with both externally mounted and pocketed sensors, including with and without insulation and thermally conductive paste.

Proximity of other heat sources to sensors

When reviewing the EMC report on heat metering errors in the RHPP, Grontmij (2014) identified a further source of error where the close proximity of a temperature sensor to the storage tank may result in conduction from the tank through the pipe compromising the accuracy of the temperature measurement.

This effect can be is easily observed under conditions of zero flow. A typical is where a temperature sensor is mounted in the cold inlet to a hot water cylinder. Over periods of no hot water use the indicated temperature creeps slowly towards the temperature of the bottom of the storage tank, and is clearly no longer a true indication of the incoming cold temperature.

However, in heat metering applications the readings of temperature sensors are only used when there is flow in the system. In this case the effect outlined is reduced, because the heat transferred by the flow is typically very much larger than any conduction through the walls of the pipework.

To determine the magnitude of this effect in heat metering applications EMC carried out a small modelling project. A particularly rigorous example was analysed, with a probe in a pipe supplying water at 10ºC to a storage tank 100mm away at a temperature of 40ºC. In this case error was approximately +0.03ºC. In the vast majority of heat metering applications the error would be of a lower order of magnitude.

In the case where the probe is mounted on the outside of the pipe, the error increased to 0.06ºC. Whilst the error is of a small magnitude, it is useful to make installers aware of the potential for this type of problems in systems with extremely low flow rates.

In conclusion this installation error has been previously shown to have a negligible impact except potentially at unusually low flow rates. For this reason this installation error has not been included in the testing program.

Heat calculation errors

Use of system working fluids other than water

Most heat meters are, by default, supplied configured to work in a system which uses pure water as the circulating fluid. The presence of a working fluid other than water introduces errors. The alternative working fluids used are generally anti-freeze solutions: in many system layouts this is essential to ensure reliable operation. These are often propylene glycol based, although there are now commercially available fluids based on de-toxified ethylene glycol.

The resulting errors in the heat metering calculation process may arise from the following:

- Depending on the meter type, calibration may be affected by the change in density or viscosity of the working fluid. In general, meters which operate from first principles to measure either mass or volume flow are not affected but meters which use, for example, the rotational speed of a turbine to infer flow may be affected significantly.
- During computation of the heat flow associated with a given set of flow and temperature readings the calculator requires the specific heat capacity of the fluid. This parameter varies according to the type and concentration of anti-freeze in the system.

Of these two sources of error, the second is the easiest to address. Data on the specific heat capacity of commercially produced anti-freeze solutions is readily available from the suppliers and can be used to calculate the impact on heat estimation. One example of the impact of propylene glycol on heat estimation calculated an error of 3% for a solution offering anti-freeze protection at temperatures to -10ºC (AECOM, 2013).

The magnitude of the first effect is harder to quantify as it is likely to be highly dependent on the flow measurement technology used. This was confirmed in the AECOM report where, the measured error for the turbine meters was as high as 8%, while the ultrasonic and vortex meters generally displayed errors of below 1%, when tested with the propylene glycol solution.

One final source of uncertainty, which cannot be addressed in the present study, lies in the amount of anti-freeze actually in any given system. As part of the EST heat pump trial (E A Technology; Gastec, 2011) the ground loops of 15 ground source heat pumps were sampled and the anti-freeze concentration measured. Concentrations ranged from 12 to 34% (corresponding to frost protection between -5 and -15ºC). In the case of a ground source system the MCS now requires that the installer check that the system is protected to at least -10ºC at the time of filling.

These results were from ground loops, and would not affect heat metering carried out for either RHI or RHPP, where measurements are made on the output of the system. However there is no reason to believe that, when a system requires anti-freeze on the output side, it is mixed to any greater accuracy than the results found. Indeed it may be that it is easier to estimate the volume (and hence the amount of concentrate required) for a ground loop than it is for a heating distribution system.

Whilst errors due to incorrect fluid parameters can easily be calculated, testing on the effect of glycol concentration is proposed as a check on the effect of this variation. The variation due to temperature is lower and it is not proposed to test for this.

In conclusion site inspections show that this installation error is quite common and the likelihood would be expected to increase as systems become older. The effect of this installation shortcoming is likely to vary with the type of heat meter. Only limited testing has so far been undertaken and therefore this effect will be included in the test schedule. The tests covered glycol concentrations of 10% to 30% since this is the most likely range to be encountered and allows interpolation for intermediate concentrations without having to extrapolate. The availability of an in-built function to correct for fluid types was confirmed and reported for each meter type tested.

Excessive sampling intervals

The rate at which a heat meter measures both temperature and flow before combining them to calculate heat can be of critical importance when measuring under dynamic conditions. In the EMC study of temperature sensor mounting (Martin, 2012) the time constant of both the immersed and the pocketed sensors tested was measured at approximately 7 seconds, although this parameter could be manufacturer dependent. In order to ensure that all data is captured, the sampling rate should therefore

be at least twice as fast as this. This is particularly important for short bursts of flow, which are generally experienced when metering domestic hot water systems, or space heating systems which short cycle (for example some heat pumps).

The sampling interval can be an issue when meters are battery operated, since a much longer sample interval is used to reduce power consumption. One particular meter switches from a perfectly adequate one second sample rate during mains operation to one minute when battery powered. In this configuration there is likely to be significant loss of temperature information, and short water run offs could be missed completely. On a system cycling at five minute intervals errors of up to 20% could be introduced.

An EST report (Gastec, 2008) concluded that the relatively slow response of the particular meter used caused errors of up to 34% when metering a standard hot water draw off sequence on condensing boilers. A similar study in Denmark found that excessive integration times are found to produce errors of up to 30%, again when measuring hot water use in apartment buildings and institutions (Bohm, 2013).

EN1434 Part 2 requires that 'The supplier shall declare how the temperature measurements and integration are related to the flow sensor signal and time' in the product data sheet.

The majority of heat meter installations are expected to be mains powered and hence it is not expected to encounter this problem in the field.

In conclusion sampling intervals are known to produce errors especially under transient operating conditions. Since only very limited laboratory testing has been carried out the test programme undertook a range of laboratory tests with varying temperature and varying flow rate. In addition tests were also undertaken in a heat pump test facility to assess the impact of real life transients such as heat pump defrost cycles which are difficult to simulate under laboratory conditions. The tests were undertaken with mains powered meters since these represent the majority of new installations. However, some heat meters in field trials, for example, may be battery powered and in these installations sampling intervals are longer (for example 1 minute for one popular heat meter model) and therefore potentially cause larger errors, depending on the type and transience of the heat load. For this reason it is recommended that battery powered heat meters are not used for RHPP monitoring.

Summary

Figure 6 summarises the discussion of the previous sections. The errors in green are those which should be addressed, wholly or in part, by the data a manufacturer is specifically expected to provide to comply with EN1434.   The errors in red are those which are not specifically addressed by EN 1434 and in particular, which do not appear in the requirements for inclusion in manufacturers' data sheets. The dashed outline denotes that information is available for only a limited number of flow meter types.

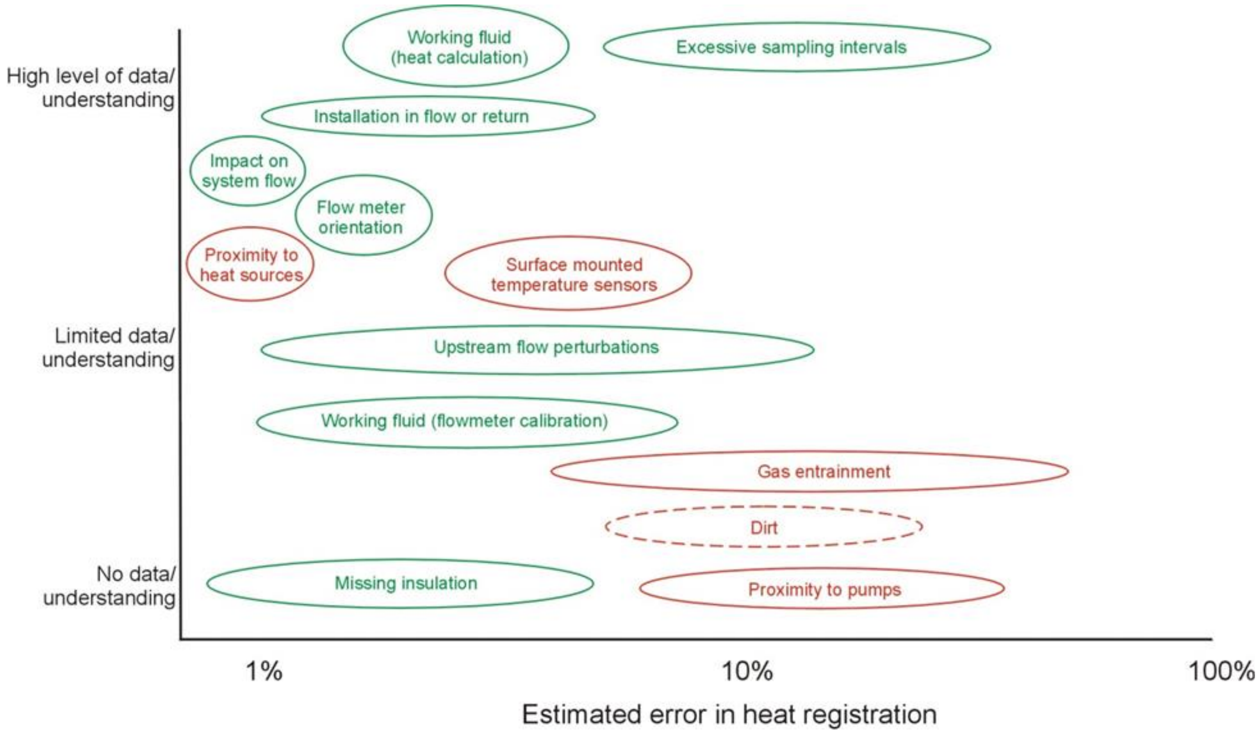


Figure 6: Current state of knowledge of heat metering errors

Loss of accuracy over time

Loss of accuracy over time can only be addressed by long term testing and this has not taken place under any of the UK field trials or laboratory tests documented in this report.

The Measuring Instrument Direct (MID, Directive 2004/22/EC) does not define the period of time required for a durability test but allows this to be estimated by the manufacturer (see the requirements of EN1434 below). Neither does the MID specify the period of time permissible before recalibration is required. Accuracy requirements have been detailed in *Heat meter accuracy*. Heat meter manufacturers do not generally state expected lifetimes or recalibration intervals, even on their calibration certificates and there is no requirement in the MID or EN1434 to do so. Note that EN1434-6 Annex B (informative) states that 'The competent authority may specify the length of time or a procedure for determining the length of time for which the initial verification certificate of the heat meter is valid. At the end of this period the heat meter would normally be replaced. Any heat meter operational, or maintenance check, should commence by checking that where an operational life has been stipulated, this has not been exceeded.' The normative part of EN1434-6 defines a 'competent authority' as 'persons or organizations charged with the responsibility for the heat meter and/or its installation.'

Some limited information on recalibration intervals has been provided by Gastec (2010) which suggests a figure of 10 years. However, any survey of lifetimes and calibration intervals is outside the scope of this project.

EN 1434-1:2007 defines reproducibility as the application of the same meter in a different location or by a different user resulting in the close agreement of successive measurements and repeatability as the application of the same meter) under the same conditions of measurement resulting in the close agreement of successive measurements, but does not stipulate over what time period. EN 1434-4:2007 specifies a durability test over one hundred days at continuous twenty four hour operation. This can be interpreted as the national requirement for durability in order to demonstrate compliance with the MID, although the directive does permit the manufacturer to (sic) 'estimate' the durability of the measuring instrument.

The accredited Kamstrup laboratory tests ultrasonic meters installed in the Danish district heating system on an annual basis. There is a legal requirement for verification or replacement of water meters in Denmark every six years (Danish Safety Technology Authority, 2006). These tests have been carried out since 1997. The 2013 report represents results based on samples of 183 lots of ultrasonic meters, representing a total of 3755 meters. These meters are of size 1.5m^3/h (domestic heating). 96.2% of meters fell within the verification limits (equivalent to the MID) and only five batches among the oldest failed, despite the fact that several of the meters were between 12 and 23 years old (Kamstrup, 2013). The 2012 report represents results based on samples of 173 lots of ultrasonic meters, representing a total of 3290 meters. These meters are of size 1.55m^3/h (domestic heating). 95.3% of meters fell within the verification limits and only six batches among the oldest failed, despite the fact that several of the meters were between 12 and 22 years old. The same tests are carried out on a smaller sample size of mechanical meters, but none of these meters attain the same level (Kamstrup, 2012).

The Kamstrup information suggests that the lifetime of ultrasonic heat meters is potentially in excess of 20 years and that the majority of heat meters between 12 and 22 years old still met the MID accuracy requirements. No errors or breakdown of the Pt temperature sensors was mentioned since the sample testing is only carried out on the flow component of the heat meter. BRE experience of using very similar PT100 sensors over long periods of time (in excess of 15 years) shows under normal conditions (excluding mechanical damage due to rough handling or accidents) there is no deterioration in accuracy or failure except under conditions of very high humidity and condensation, usually when measuring chilled water temperature. It is thought that under these conditions moisture can sometimes enter the PT100 metal sheaf and cause loss of accuracy and failure, possibly through corrosion and the wire connections. EN 1434-4 specifies three 24 hour damp heat tests under condensing conditions but clearly cannot reproduce exposure to long term damp / condensation conditions. No tests on temperature sensor deterioration over time are being recommended.

The BRE utilises electromagnetic type meters for various flow testing rigs and reference is being made to the historical calibration certificates for one of these meters, dating back to Jan 2005. Figure 7 shows the data and clearly demonstrates that there has been no deterioration of performance over time, with the measured mean error falling between +1.65% and -1% over the ten year period. This is well within the range of a Class 1 flow meter.

For the case of mechanical flow meters, a case study of domestic cold water single jet meters tested more than 600 meters of different models and ages from households in Spain (Arregui, Pardo, Parra, & Soriano, 2007). The majority of the meters (over 75%) consisted of two different models. The results obtained for the weighted error of these two types of meter are shown below in Table 6.

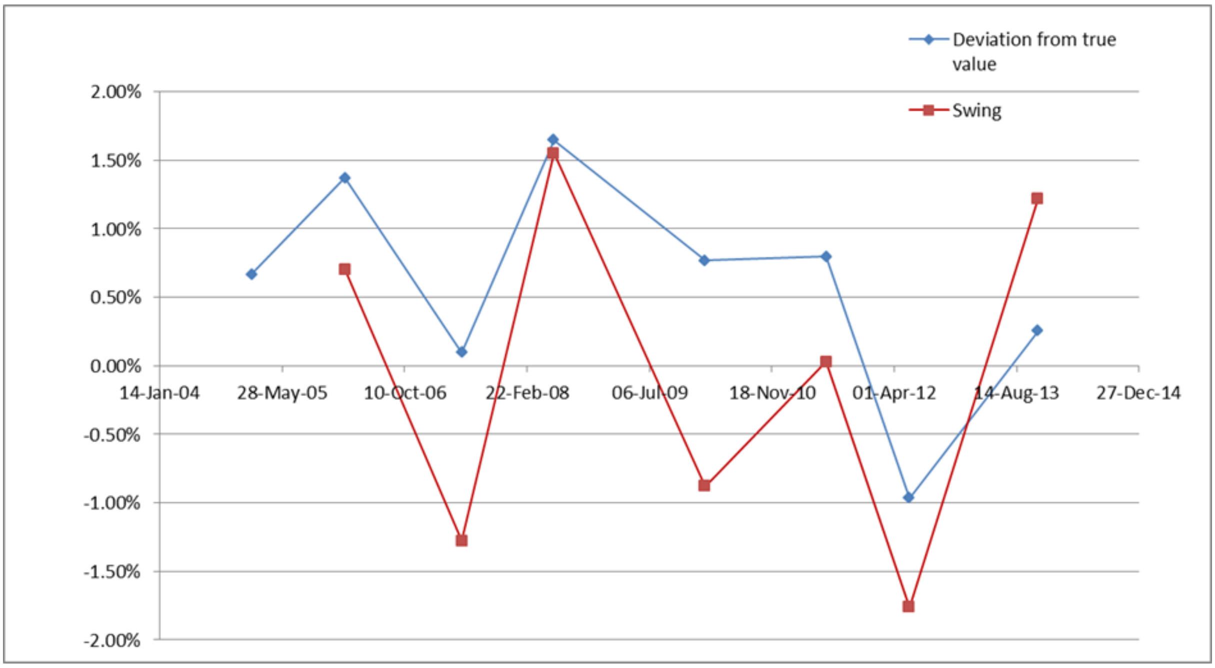


Figure 7: Historic Calibration Data for Electromagnetic Flow Meter

Water meter model 1

Age	Meters which serve water directly to the user	Meters installed upstream of a storage tank[6]
1-3 years	-7%	-12%
4-5 years	-8%	-16%
6-8 years	-7%	-17%

Water meter model 2

Age	Meters which serve water directly to the user	Meters installed upstream of a storage tank
8-9 years	-11%	-23%
10-11 years	-13%	-28%
12-14 years	-12%	-26%

Table 6: Weighted errors for over 600 mechanical water flow meters installed in Spain

[6] The flow pattern upstream of a storage tank is different from the flow pattern when there is no tank, with the tank smoothing out demand. Mechanical meters are more susceptible to error at low flow rates.

The study identified that that water quality was an important factor in the rate of deterioration (water temperature is unlikely to be a factor since). However, it appeared that this parameter did not affect all meters in the same manner since other unidentified factors produced dissimilar results amongst specific water meters installed in adjacent locations. Another parameter that plays a major role in the rate of deterioration of mechanical meters is the mechanical robustness of components. A significant number of meter failures were attributed to breakage of the turbine and bearing or gear wear. This is evidence that the long term durability of mechanical meters is potentially inferior to ultrasonic and other meter types that do not have mechanical moving parts.

In conclusion the MID does not does not define specify durability requirements or lifetimes and EN 1434-4:2007 specifies a durability test over one hundred days at continuous twenty four hour operation. EN 1434-4:2007 also specifies three 24 hour tests under condensing conditions. These tests cannot provide total confidence in either long term accuracy or durability and this could only be provided by long term testing. However, the Kamstrup sample testing does at least give confidence in the long accuracy and durability of this particular make of ultrasonic heat meter. The literature review did not identify any similar long term sample testing undertaken by any other manufacturer. However, it is clear that if the Kamstrup meters are representative of other makes of ultrasonic meters then similar levels of long term accuracy and lifetime should be expected.

As part of the test program it is proposed to test a number (six) of meters that have been installed in domestic heating installations for approximately three years and to compare the accuracy of these meters with the new meters under test.

Review of currently installed RHI heat meters

This section of the report is partly based on an analysis of data supplied by DECC on currently installed RHI meters.

Distribution by manufacturer and meter type

An analysis of the Ofgem database of non-domestic RHI heat meter installations (provided by DECC to BRE, 7 January 2015) has been undertaken. This shows that the majority of heat meter types are ultrasonic with the second most numerous type being vortex. A smaller number of mechanical models were identified. The number of electromagnetic meters is negligible. A classification of the database by meter type is shown in Figure 8.

A separate literature survey carried out as part of this research and contact with a number of manufacturers and heat meter suppliers has indicated that electromagnetic meters are rarely selected for heat metering applications on the UK market. However, it appears that electromagnetic are still widely used in Russia and the former Soviet Union territories. The manufacturers of these include several Eastern European former soviet bloc countries. Manufacturers' publications (Prseworski & Sukovic, 2000) appear to indicate that electromagnetic meters have been largely superseded by ultrasonic meters and this is also confirmed by EU market data (Centre for Strategy & Evaluation Services, 2010).

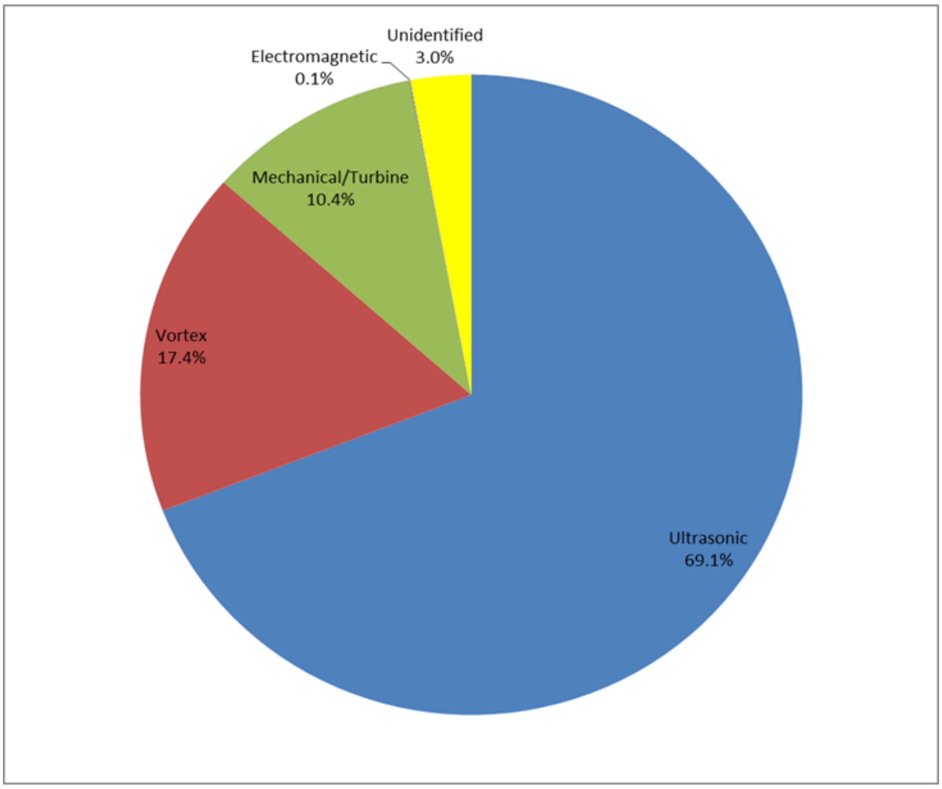


Figure 8: Analysis of heat meter types from the non-domestic RHI database (provided by DECC)

Type	Number	%
Ultrasonic	14761	69.1%
Vortex	3724	17.4%
Mechanical	2231	10.4%
Electromagnetic	11	0.1%
Unknown	631	3.0%
Total	**21358**	

Table 7: Analysis of the non-domestic RHI heat meter database – breakdown by type

Type	Number	%
Ultrasonic	161	40%
Vortex	184	45%
Mechanical	47	12%
Unknown	13	3%
Total	**405**	

Table 8: Analysis of the domestic RHI heat meter database – breakdown by type

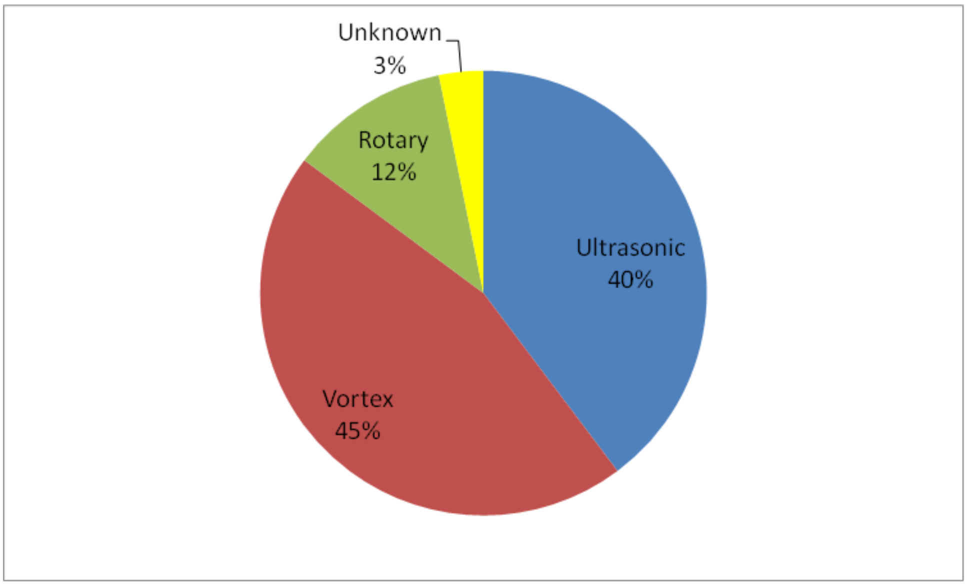


Figure 9: Breakdown of the RHI domestic heat meter database by meter type

An analysis of the Ofgem database of domestic RHI heat meter installations (provided by DECC to BRE, 27 January 2015) has also been undertaken and the numbers of each type are also shown in Table 8 and Figure 9. This shows that the majority of heat meters installed are vortex with ultrasonic as the second most numerous type. A smaller number of mechanical models were identified. There were no electromagnetic meters. This database is made up of just over 400 meters representing some 2% of actual domestic RHI installations, since the requirement for metering was not compulsory. It is interesting to note that the meters are practically all MID Class 2 although MID Class 3 is acceptable for domestic RHI metering.

Outline of test programme

The main scope of the test program was the identification and quantification of heat meter installation effects and heating system set-up effects on heat meter accuracy.

Heat meters are certified to meet the requirements of the relevant class of the MID, and this means that their accuracy has to fall within established parameters. Manufacturers test their meters to ensure that they comply with the directive, but they also establish installation parameter boundaries which have to be met. No linkage between poor or non-compliant installation and inaccuracy is supplied by manufacturers. Conditions in the field do not always allow the facility of an ideal installation[7] and may deviate by a small or larger degree. The main scope of the test program was the identification and quantification of heat meter installation effects and heating system set-up effects on heat meter accuracy.

Selection of meters for testing

In order to define a test program it is necessary to establish selection criteria for choosing the meters to be tested. Time and budget constraints prevent testing all available meters on the market, so the selection was defined to include the most cost-effective options, representative of what is being installed under the RHI and what might be installed in future field trials.

The analysis of installed heat meters registered in the RHI database indicated that over 60% of the installed meters are of the ultrasonic type, with a further 17% are of the vortex type. The remainder of the market (under 20%) is fragmented amongst over 20 different brands. No electromagnetic type meters could be clearly identified from the database.

The outcome of this analysis was for BRE to recommend the heat meter selection for testing shown in Table 9 which was agreed by DECC.

[7] Although both the domestic and the non-domestic RHI scheme regulations require heat meters to be installed in accordance with the manufacturer's recommendations.

2 samples of each type & size	Type (for water)	DN25	DN 40
A	Ultrasonic	X	X
B	Vortex	X	X
C	Ultrasonic	X	
D	Multi Jet	X	

Table 9: Breakdown of heat meter types and sizes to be tested

Note that the flow measurement part of the Sontex is claimed by the manufacturer to be based on the 'fluid oscillation' principle and is therefore a variant of the classic vortex flow meter.

The calibrated flow meters used by BRE are of the electromagnetic type and hence it was decided to exclude the electromagnetic type meters from the testing of new heat meters and to test two brands of ultrasonic meters instead, these being more representative of the installed stock. The dimensions selected for testing (DN 25 and DN40) are representative of the non-domestic market.

Whilst testing two different brands of ultrasonic meters may result in similar findings, this is still a useful result, when one considers the dominant placing of this technology on the market.

The mechanical type meters referred to as turbine meters in the tender specification have been replaced by multi jet type meters in the market and hence these have been selected for testing. Multi-jet is the industry standard for domestic water meters. This means that they are the technology of choice for heat meter suppliers wanting a reasonably reliable readily available flow meter, since the market for water meters is the predominant market in flow metering in terms of quantity.

It should be pointed out that although the Metering and Monitoring Service Packages Technical Supplement published by DECC (12th July 2013) generally recommends that heat meters should have resolution of one pulse per Watt hour most suppliers are offering a resolution of one pulse per kilowatt hour.

The analysis of installed meters from the domestic RHI, albeit over a small sample size, also indicated a predominance of ultrasonic and vortex type meters, confirming the above.

All four makes proposed for testing are MID-2 as a minimum with one manufacturer, claiming MID-1. MID-2 is representative of the installed database as demonstrated in report section *Distribution by manufacturer and meter type*.

Definition of tests

The proposed range of tests can be broadly divided into three groups:

a) Tests to investigate the effect of incorrect installation

b) Tests to replicate the effect of field conditions

c) Calibration tests

These tests are intended to obtain a level of confidence that the meters meet the manufacturers' specifications and that the pairs of meters from the same manufacturer are actually comparable.

These tests are designed to determine the accuracy of each type of flow meter over the complete operating flow range, and within the temperature range determined by practical application limits. This establishes the effect of operating at the limits of the meter design flow rates especially since some meters tend to have a higher percentage error at low flow rates. The tests also give some indication on the effects of incorrect meter sizing.

Two types of each new heat meter are to be tested to assess variability. Tests are to be carried out over a range of five different flow rates. Six used meters removed from an operational site are also to be tested under the same procedure. The scope of the tests on the new meters is to determine whether and to what extend the accuracy of the heat meter is affected by temperature, flow rate and meter type. The tests on the used meters should give an indication of the possible deterioration in performance over time.

Tests to investigate the effect of incorrect installation

AECOM and Arregui previously undertook testing of these effects. However, the meter orientation tests should be repeated to be able to provide data for cumulative error estimation. Heat meter orientation is known to increase the susceptibility of meters to other factors, in particular air and dirt, but this interdependency has not been previously tested. It is important to understand and quantify the sensitivity so that the effect on the accuracy of heat meters in the field can be predicted.

There is a very high likelihood in practice of errors caused by flow disturbances. More comprehensive testing is required especially to establish the sensitivity to the level of flow perturbation (and the effect of) slight and large deviations from the manufacturer's recommended installation. Flow disturbances may include a single bend or several bends, air/gas entrainment, pump installation in the immediate vicinity of the meter, and low static pressure (cavitation risk) such as could occur when a heat meter is installed on the inlet side of the pump.

Entrained air is a very common fault in heating systems but has not been fully tested and especially not in conjunction with incorrect orientation and other flow distances whose effect may be magnified by the presence of entrained air.

Errors between the heat meter calculator calculation parameters and system parameters include

1. Incorrect fluid parameters e.g., temperature, glycol concentration
2. Low sampling rates (for battery operated meters)
3. Unsteady flow

Whilst errors due to incorrect fluid parameters can easily be calculated, testing on the effect of glycol concentration is proposed as a check on the effect of this variation. The variation due to temperature is lower and it is not proposed to test for this.

Tests have been carried out to identify the errors caused by low sampling rates. It is proposed to exclude battery powered meters from the majority of tests. However, if time and budget constraints permit, it is proposed to try the battery meters on the intermittent flow test rig to assess the cumulative error caused by battery power and intermittent flow concurrently.

Incorrect temperature sensor installation was a very common fault in RHPP site audits. It may be caused by poor choice of sensor or poor installation of the sensors including strap-on sensors. Some tests have already carried out by EMC and Graham Energy but one comprehensive data set is required for a clearer analysis of the error arising from this. This error type also creates an opportunity or higher risk of fraud and tampering. Testing carried out to include effect of heat transfer/conductive paste.

The testing described above should wherever possible be carried out by comparison, with one meter immediately adjacent to the disturbance with second meter installed correctly. Where significant errors are noted additional test with varying distance between meter and disturbance were carried out to establish the sensitivity.

A series of tests are to be carried out on one representative sample of each type of meter. The test rig is to simulate different installation scenarios, namely:

a) Meter installed in close proximity before and after flow pump

b) Meter installed in close proximity to one or more 90˚ bends, before and after meter

c) Air entrained in flow, with and without bends, with and without incorrect orientation of meter

d) Incorrect meter orientation, with and without bends on inlet.

e) Incorrect fluid in system, with different concentrations of antifreeze on meters configured for water.

f) Various incorrect temperature sensor installations, under both steady state and cycling on/off conditions.

The scope of these tests is to determine the effect of different installation characteristics on the accuracy of each type of meter. A number of the installation characteristics are to be applied singly and in combination.

Tests to replicate field conditions

Researchers have regularly highlighted the fact that testing of heat meters in laboratory conditions is considerably different for practical applications.

In particular dirt is a very common fault in heating systems but no prior testing has been undertaken since this is difficult to achieve in a laboratory environment. The likelihood of the effect of dirt increases with time and may have a bearing on meter accuracy over time. The proposed test method therefore includes testing in a house with an existing ‘dirty’ heating system to avoid the limitations of laboratory test rig testing.

Transient operating conditions, which are especially likely with heat pump systems, could result in large errors particularly since heat pumps often operate with small temperature differences between the water flow and return. Transient conditions are difficult to simulate in the laboratory in a repeatable manner and therefore there is little data on the effect on heat meter accuracy. The proposed test method therefore includes testing in a heat pump test rig to avoid the limitations of laboratory test rig testing.

The following tests are intended to test one of each type of meter in conditions that simulate practical applications. These tests also included an electromagnetic meter.

a) Testing of meters on air source heat pump test rig whilst heat pump is operating in transient mode, i.e. incorporating defrost cycles.

b) Testing of meters on a test rig with cycling flow rates.

c) Long term testing of meters (between two to four weeks) on test house with ‘dirty’ installation.

The scope of these tests is to determine meter accuracy under conditions similar to those found in actual heat pump installations. (Heat pump installations are more onerous in terms of low temperature difference and fast transients, compared to, for example, biomass systems).

Other factors affecting accuracy

A number of additional long term operational and lifetime factors, including long term calibration stability, reliability and system cleanliness and flushing may also affect heat meter accuracy over time, but these cannot be addressed directly by this test programme.

However, the results from the test programme may inform these questions and provide additional information on the sensitivity of long term accuracy on them. For example, the tests could determine the sensitivity of different types of heat meter to factors such as dirt and air that may have a long term impact on accuracy, and also how factors such as orientation may affect this sensitivity.

The examination and testing of old heat meters should also provide information on the effect of dirt on accuracy.

Tampering/fraud risk

Heat meter manufacturers provide protective devices which can be sealed both before and after installation to deter deliberate tampering, removal or adjustment by making such interference visually detectable. Examples include self-adhesive ‘sticker seals’ over screws and sticker seals and crimped wires between components such as the lid and body of the calculator unit. Examples are shown below in Figure 10 and Figure 11. Testing of these aspects is outside the scope of this project. However, where installation effects may create an opportunity for fraud this is to be noted during the testing programme and reported. Of particular concern to DECC is the possibility of over reporting delivered energy from renewable heat generators as part of the RHI and RHPP. Therefore the possible level of over reporting should be assessed and reported. For example, strap-on temperature sensors are considered to be a particularly high risk, especially under fluctuating temperature conditions. These conditions were therefore tested both individually and in combination in our test programme.

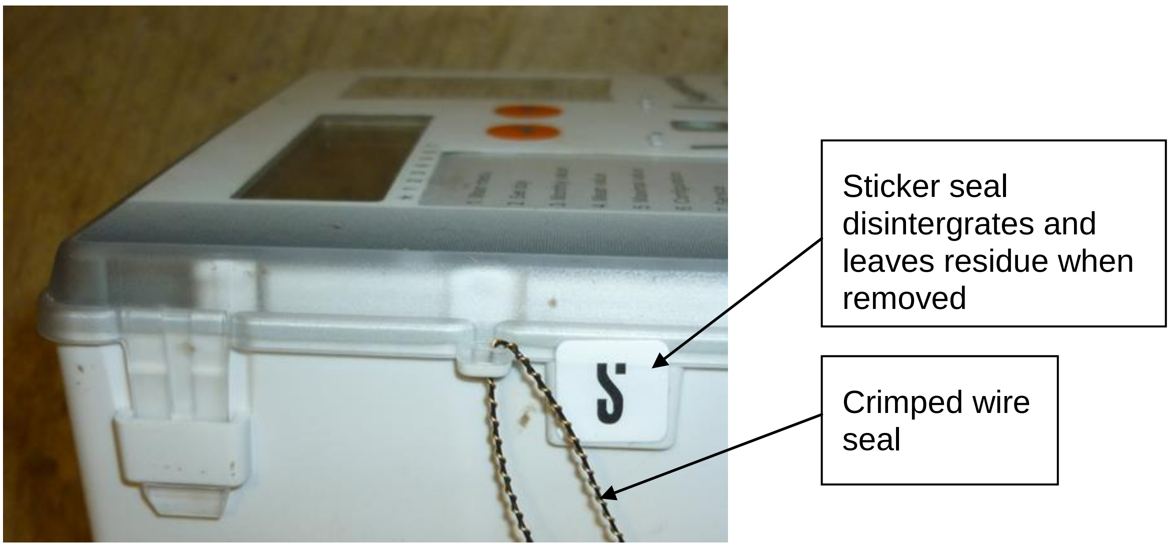


Figure 10: Sticker seal and crimped wire seal on top cover of calculator unit

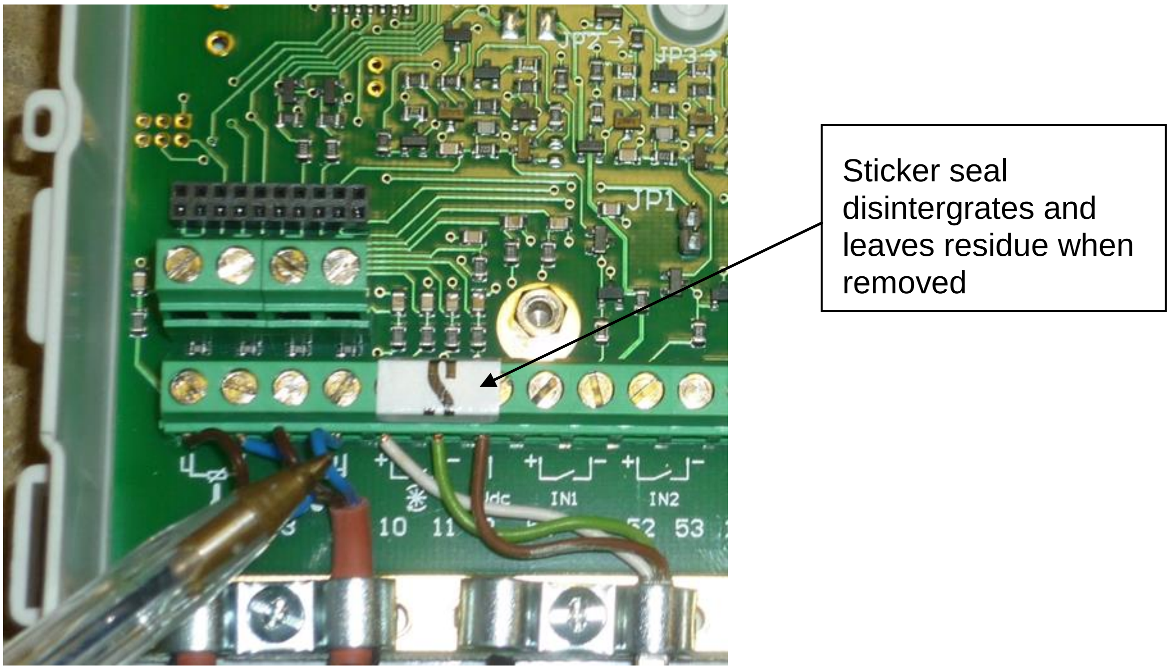


Figure 11: Sticker seal over electrical terminal screws for flow meter connection cable

Cumulative errors

It is highly probable that many individual errors are relatively small but that there is a high risk that cumulative errors from the combined effect of several installation effects and the effect of fluctuating and cycling operating conditions may result in larger errors. For example previous testing has indicated the potential for temperature sensor installation to cause large errors in conjunction with fluctuating flow temperature. For this reason Test Set 4 (see Appendix C) was intended to test different temperature sensor mounting under steady and fluctuating flow temperature conditions.

Data interfacing

Under the MID the basic functional requirement for a heat meter intended for utility measurement is a display that must be accessible to the consumer. At the most basic level this may therefore be the quantity of heat energy metered. This is typically displayed in kWh or MWh. Although many heat meter manufacturers offer a range of energy unit resolutions based on the purchasers' requirements specified at time of purchase this cannot be subsequently altered without the meter being returned to the manufacturer. Different models of heat meter also have different limits on the level of resolution available which means that some models may be more suitable than others for detailed field trials. All of the heat meters tested as part of this project provided the ability to scroll the displayed value through energy, water volume, flow rate, power and the temperature value from both temperature sensors. The energy resolution of the meters tested varied between 1 Wh to 100 kWh. Clearly models with an energy resolution of 100 kWh would be less suitable for energy monitoring research projects.

In addition to a display the heat meter may also have a facility to be remotely read. At the most basic level many heat meters currently on the market have a pulsed energy output and a pulsed water volume output. Pulse outputs can be read by a wide range of data loggers and Building Management Systems (BMS). The pulse resolution (for example number of pulses per kWh or MWh, and sometimes Wh) would be an important consideration when selecting a heat meter model for field trial purposes. It was found during the testing programme that one model of energy meter supplied at BRE's request with a 1 Wh energy pulse had an upper limit on the rate of energy pulses and this must therefore be carefully considered when specifying meters with such high resolutions for field trial purposes.

All of the heat meters tested had a manufacturer option to fit an M-Bus communication module. The M-Bus is a data communications bus system developed by the industry specifically for remote communication with energy and water meters. Most of the M-Bus communications modules require communication using the industry standard MODBUS protocol which is an international standard for communication between devices connected as part of a an industrial control system or BMS. A key feature of the M-Bus is that it allows many meters to be connected to one bus by using an addressing protocol and also it provides a larger range of data. The connection is usually by wire but wireless options are offered by some manufacturers. A heat meter receiving a data request on the M-Bus would normally reply by sending a 'frame' of data. A frame would normally contain some manufacturer specific data (relating to the meter type and configuration) plus the following actual data (this varies between meter model and in some cases custom data frames may be specified by the user):

- Data and Time
- Energy
- Volume
- Hour counter
- Supply temperature
- Return temperature
- Temperature difference
- Actual power
- Maximum power
- Actual flow
- Maximum flow

Utilisation of the M-Bus requires special software and hardware interfacing and set-up with the host computer used for data gathering and may therefore be unsuitable with simple or low cost remote data logging systems.

Test programme, test strategy and test prioritisation

Appendix B summaries the test strategy and prioritisation discussed above in a graphical form. The colour coding defines the priority levels for the test programme. Further analysis of the test programme is summarised in the charts in Appendix D.

Specific details of the test programme and test apparatus are provided in Appendix C.

Data from test programme

The test programme (see Appendix C) necessitated the collection of the energy, temperature difference and flow measurements from the heat meters, with a requirement for instantaneous, periodic, and cumulative values. Wherever possible these readings were obtained from the meter energy and volume pulse outputs using a data logger. However, some specific models of heat meter had very low resolution energy pulses (10 kWh per pulse) and therefore for some tests instantaneous power readings were taken by manually reading the LCD panel on the calculator unit or by collecting instantaneous power readings through the M-BUS (Meter Bus). M-BUS data was read to a PC using a proprietary M-BUS (Meter Bus) to USB converter unit. A number of the sample heat meters were purchased with an optional M-BUS output interface and this allowed energy, fluid volume, power, flow rate, sensor temperature and temperature difference to be read and recorded automatically to a PC. This required special software to be written specifically for this research project but importantly demonstrated the potential for this additional data to be collated in monitoring field trials using the heat meter without the need for additional sensors.

In all instances the errors reported are the actual errors measured in each specific test and no corrections have been applied to any of the measurements.

Calibration testing – flow measurement

Calibration tests have been undertaken on two samples of the following four types of DN25 heat meter and two types of DN40 heat meter, as detailed in Table 10. All samples were new units supplied by UK distributors and are therefore representative of units installed in the UK.

	DN25	Nominal flow rate, q_p[8] (m^3/h)	DN40	Nominal flow rate, q_p[8] (m^3/h)
1	Ultrasonic A and B	3.5	Ultrasonic A and B	10
2	Vortex A and B	3.5	Vortex A and B	10
3	Ultrasonic C and D	3.5		
4	Rotary A and B	3.5		

Table 10: DN25 heat meters calibration tests

[8] qp is defined in the MID and EN 1434 as the highest value of q (flow rate) that is permitted permanently for the heat meter to function correctly).

1 qp is defined in the MID and EN 1434 as the highest value of q (flow rate) that is permitted permanently for the heat meter to function correctly).

The results are plotted in terms of percentage error for flow rate and energy, compared to a calibrated standard flow meter instrument and calibrated high precision temperature sensor probes. Details of both the test method and reference instrument and sensor calibration are provided in report section *Outline of test programme*. The graphical plots also include the MID class 2 and class 3 maximum permissible errors. Tables showing derivation of the MID maximum permitted errors for the values of qp shown in Table 10 are provided in Appendix E.

	Nominal dim.	Nominal flow q_p		Minimum flow q_p		Maximum flow q_p		Pressure loss
	(mm)	(m^3/h)	l/s	(m^3/h)	l/s	(m^3/h)	l/s	Δp@q_p (bar)
Ultrasonic A and B	28	3.5	0.97	0.035	0.01	7	1.94	0.07
Ultrasonic A and B	40	10	2.78	0.1	0.03	20	5.56	0.06
Vortex A and B	28	3.5	0.97	0.035	0.01	7	1.94	0.16
Vortex A and B	40	10	2.78	0.1	0.03	20	5.56	0.25
Ultrasonic C and D	28	3.5	0.97	0.35	0.01	7	1.94	0.11
Rotary A and B	28	3.5	0.97			7	1.94	

Table 11: Manufacturers' specifications for heat meters tested

The DN25 meters were each tested at 5 flow rates between 0.05 and 2.0 l/s with a 5K temperature difference (sensors at 40°C and 45°C), and one flow rate (1.0 l/s) at 3K (sensors at 30°C and 33°C) and 10K temperature difference (sensors at 55°C and 65°C). The range of flow rates allowed by the manufacturers of the various meters tested are tabulated in Table 11 above.

The DN40 meters were each tested with a 5K temperature difference (sensors at 40°C and 45°C).

Percentage flow rate and energy errors from the tests are shown graphically in Figure 12 to Figure 15 for the DN25 meters and Figure 16 and Figure 17 for the DN40 meters.

Figure 12 presents the results of the calibration testing flow measurements on eight new DN25 heat meters. The graph indicates that none of the meters meet the MID Class 2 requirements for flow measurement over the range of flow rates tested, and most of the meters are actually outside the MID Class 3 requirements. Figure 17 presents similar results for four new DN40 heat meters. In this case the meters are generally within the MID Class 2 requirements for flow measurement, except at very low flow rates.

The presentation of the results and the fact that the flow measurements for the DN25 meters lie outside the maximum permitted total error can and should raise a number of concerns.

The immediate assumption is to question the reliability of the calibration meter, but over the period of testing three different calibrated meters were used and cross checked against each other. The calibration meters were independently calibrated by a UKAS accredited laboratory before the testing commenced.

The flow measurements recorded by the eight DN25 heat meters demonstrate a nearly constant over measurement of the flow rate of between 2 and 4%, except at very low flow rates.   The mean error is +2.36% and the mean standard deviation is 0.66, excluding the outliers at very low flow rates.

This indicates that the DN 25 heat meter flow measurements demonstrate a high degree of stability, with the whole group outputting the same measured values with minimal scattering, and this is regardless of the absolute accuracy of the individual values measured. In the absence of any other explanation to justify the difference in flow measurement between the new heat meters and the calibrated control meters, the variances between the measurements recorded by the control meter and the DN25 meters could related to possible differences between the manufacturers' calibration conditions and the tests carried out. In any case, these variances are stable over the range of measurement of the heat meters and can be taken into account mathematically in order to perform test measurements with minimal uncertainty.

The DN40 meter measurements show an average over measurement of the flow rate of approximately 1.8% for both the vortex type meters whilst both ultrasonic meters show small variations around the zero error mark. The standard deviation for the vortex type meters is approximately 1.0 whilst for the ultrasonic meters it is approximately 0.65. Measurements at the minimum flow rates have again not been considered for this analysis.

As noted above for the DN25 heat meter flow measurements, the DN 40 heat meter flow measurements demonstrate a high degree of stability with minimal scattering.

Figure 13, Figure 14, Figure 15 and Figure 17 present the results of the calibration testing energy measurements on eight new DN25 heat meters and four new DN40 heat meters. The graph indicates that all the meters meet the MID Class 2 requirements for energy measurement over the range of flow rates and temperatures tested, with the exception of two outlying points at very low flow rates for the DN40 vortex meters. In view of the fact that the DN25 meters generally did not comply with the MID class 2 requirements for flow measurement, this means that either the accuracy of the temperature measurement and calculator are compensating for the possible inaccuracy of the flow measurement, or that the meters are being calibrated as a single unit by the manufacturers and not as individual components.   The MID defines a maximum permissible error (MPE) for the flow sensor, the temperature sensor pair, and the calculator, as well as an overall MPE for the heat meter. Technically, non-compliance with the flow sensor MPE implies that the heat meters are also non-compliant, but it seems unlikely that four manufacturers would put non-compliant meters on the market. This is an area where further testing is recommended before drawing any firm conclusion.

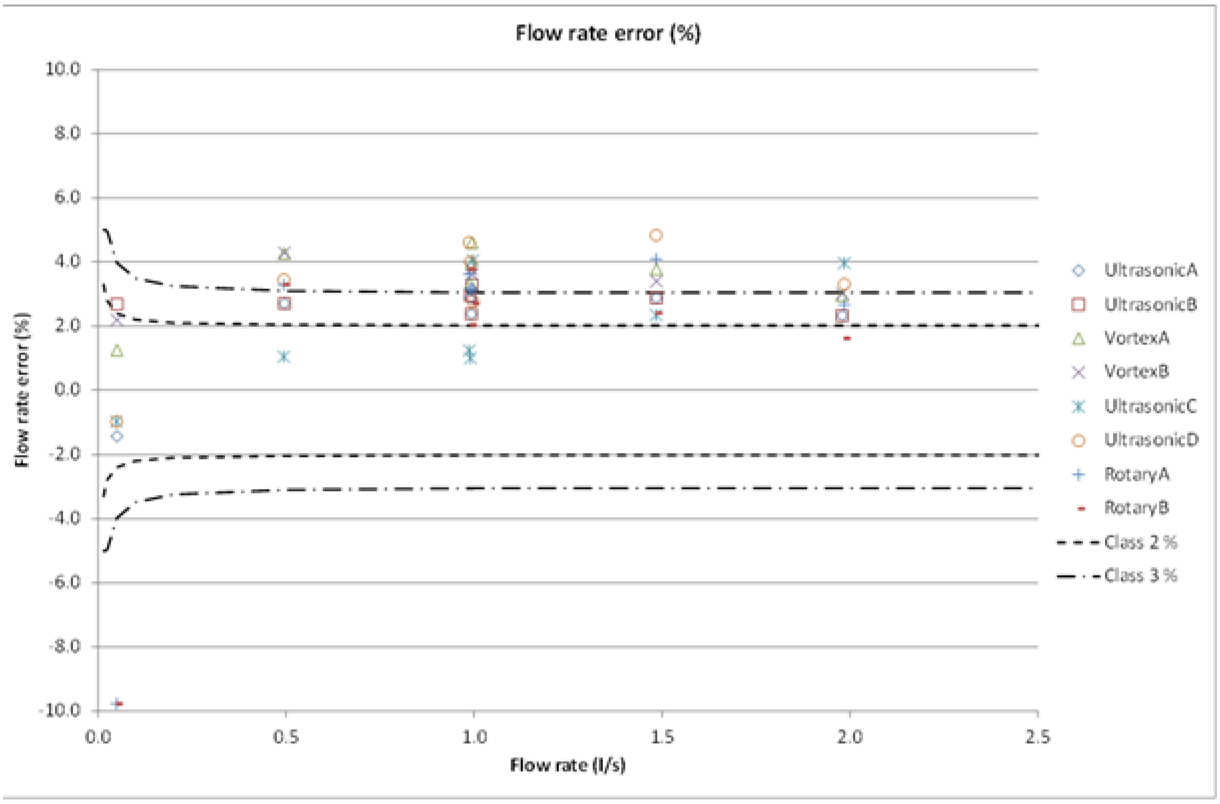


Figure 12: DN25 heat meter flow rate error

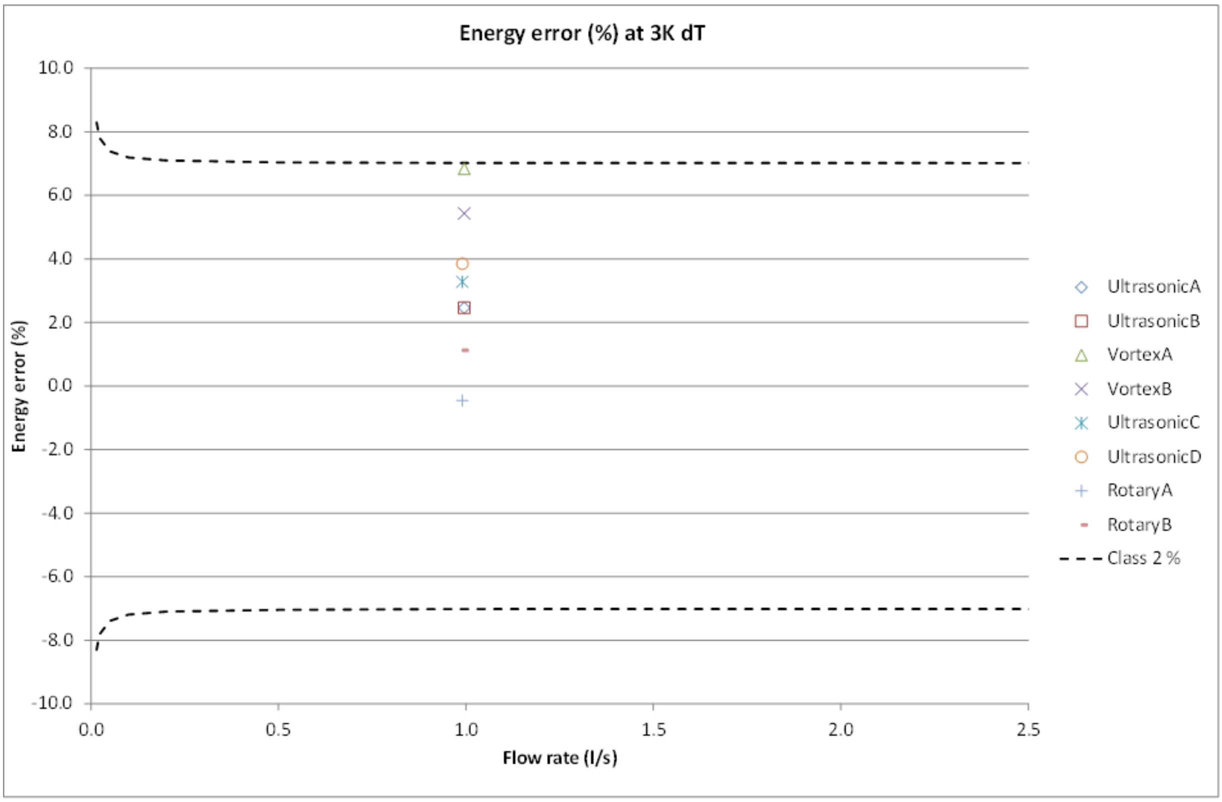


Figure 13: DN25 heat meter energy error (at 3K temperature difference)

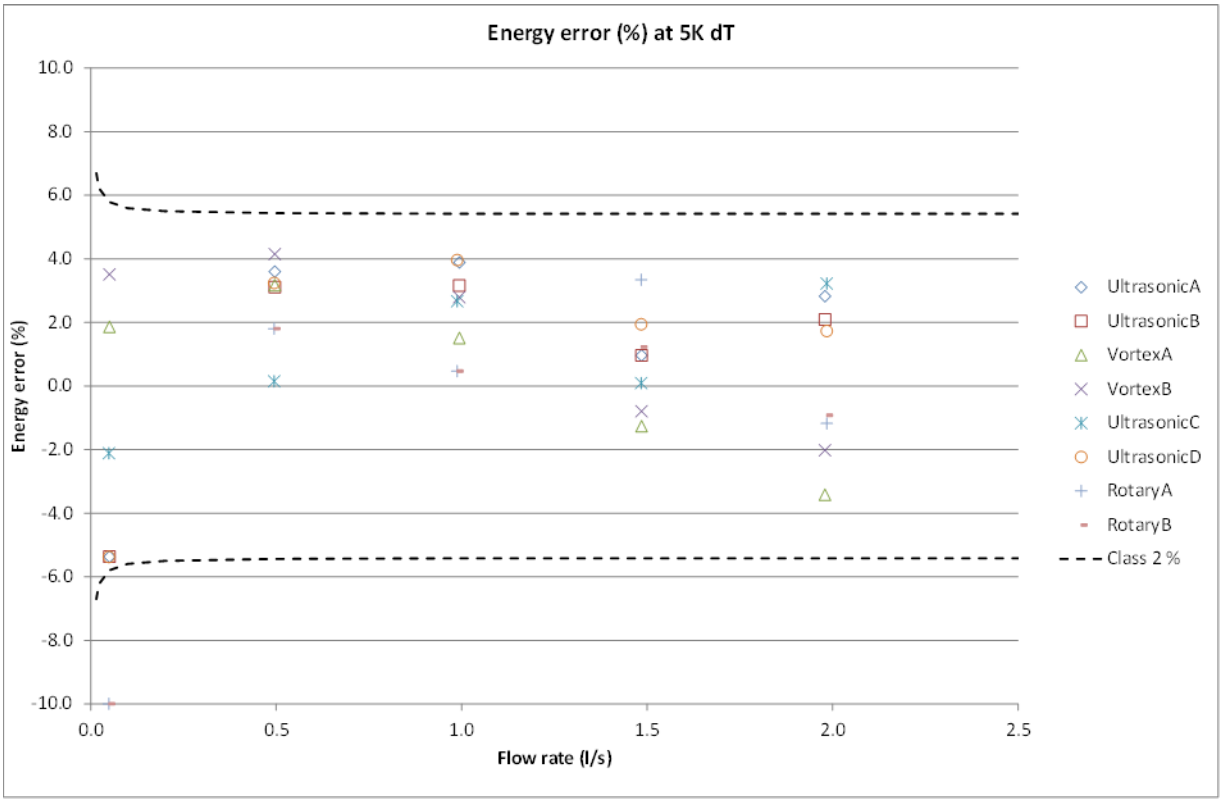


Figure 14: DN25 heat meter energy error (at 5K temperature difference)

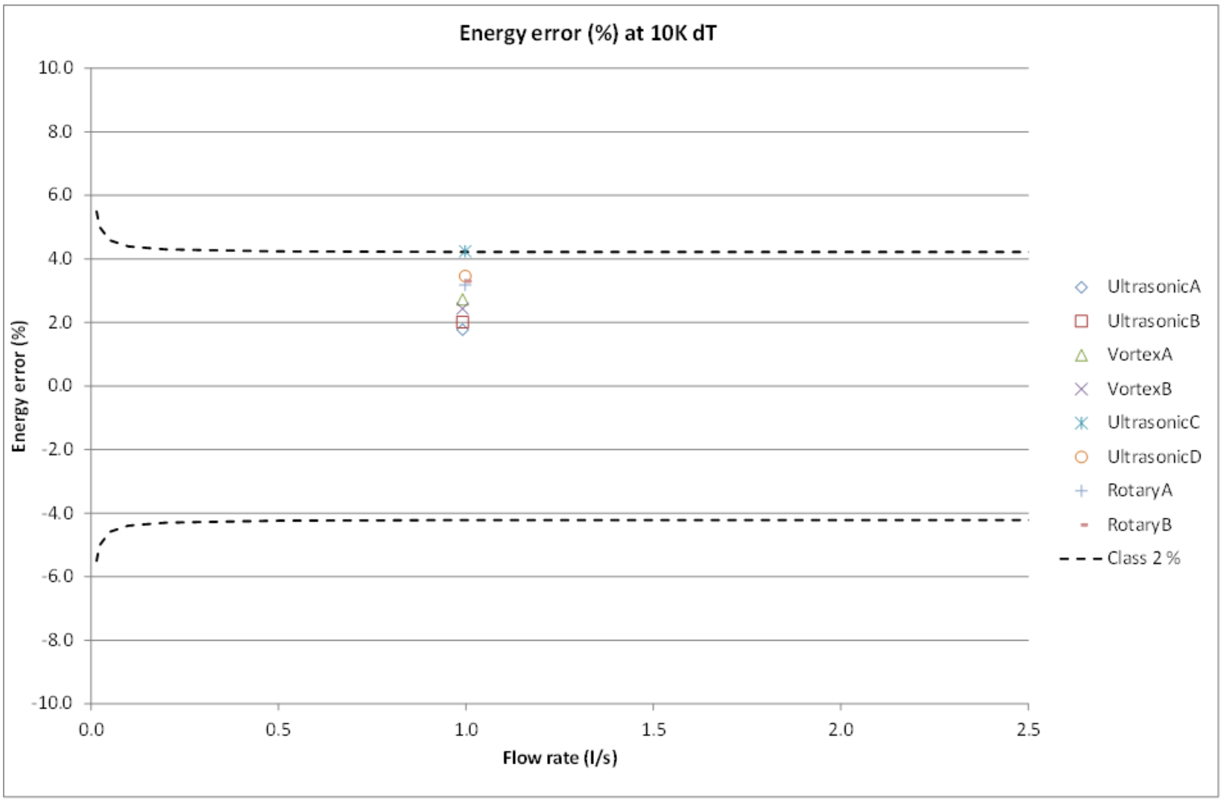


Figure 15: DN25 heat meter energy error (at 10K temperature difference)

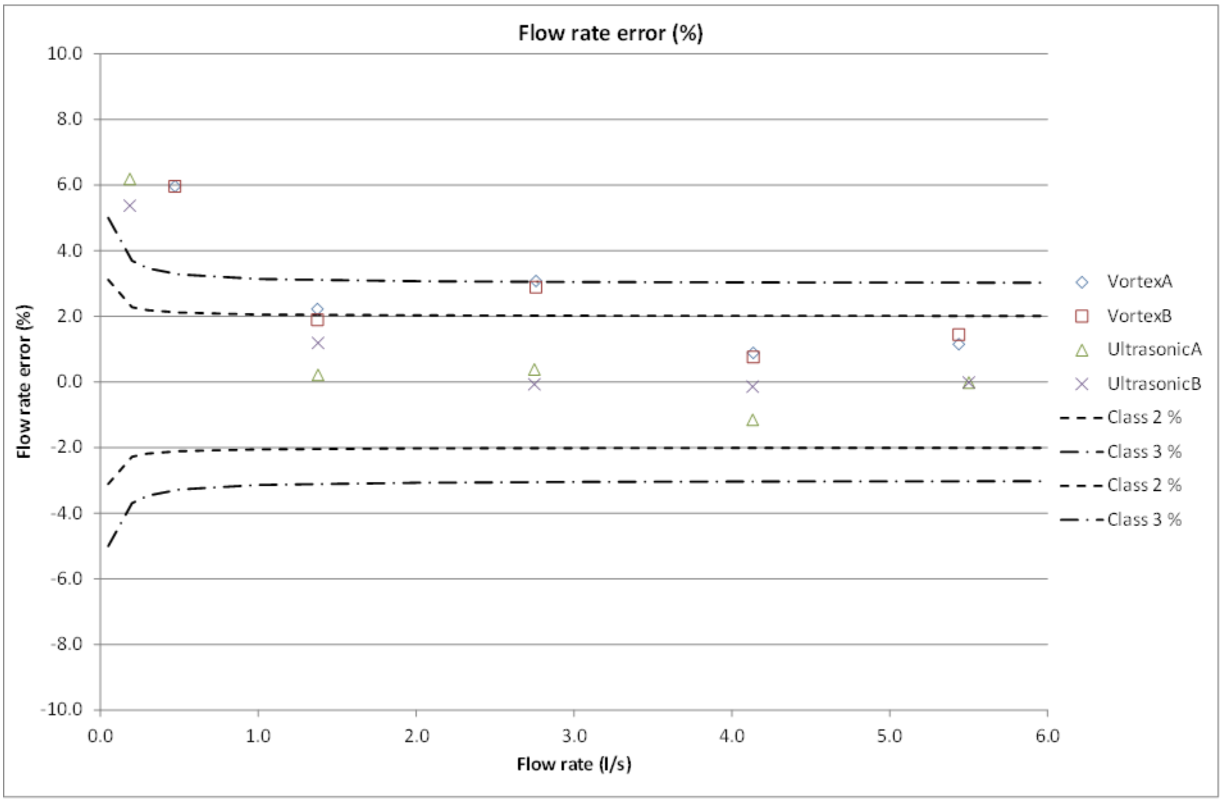


Figure 16: DN40 heat meter flow rate error

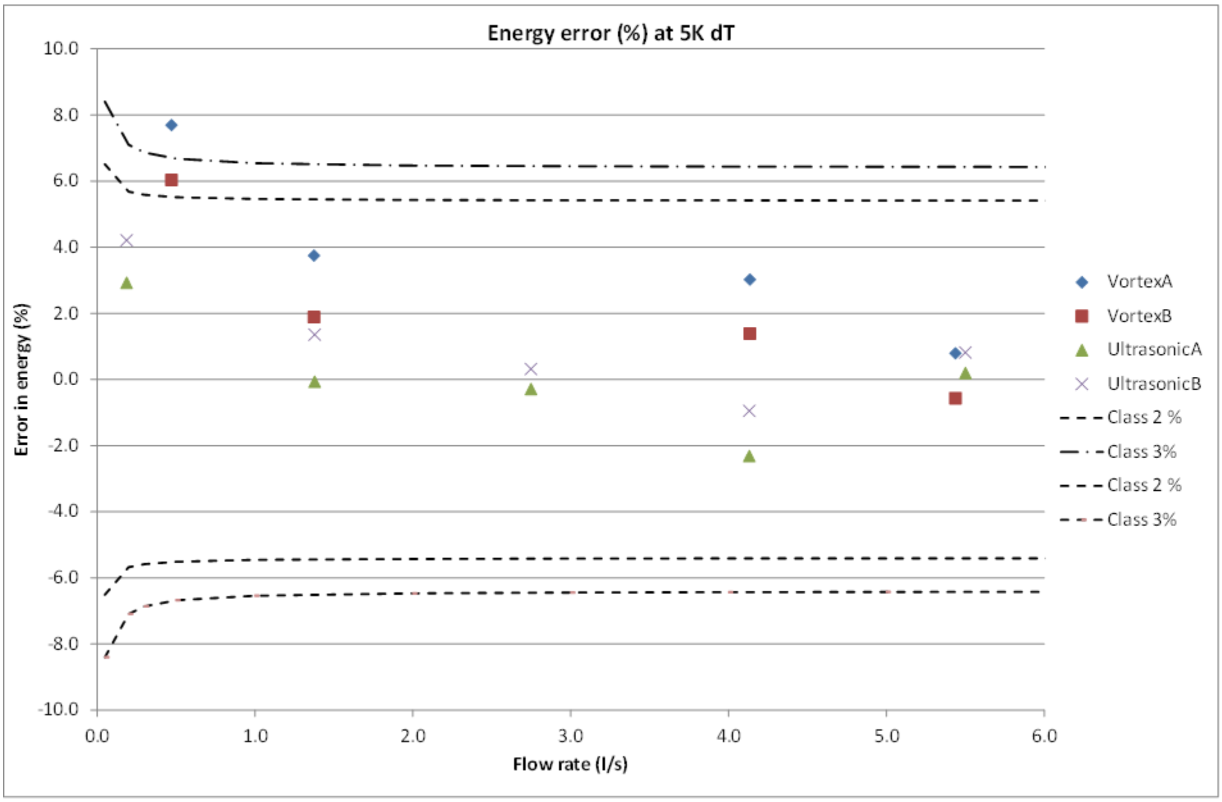


Figure 17: DN40 heat meter energy error (at 5K temperature difference)

Testing of disturbances to flow

Whilst the calibration type tests were carried out on both the DN25 and the DN 40 meters, the tests to determine installation effects were carried out on the DN25 meters only, since all four meter types under test were only available in this dimension. The following tests were carried out with two samples of each DN25 heat meter type:

1. Incorrect orientation
2. Air entrainment within flow
3. Disturbances to flow (bends in close proximity)
4. Installation in close proximity to pump

This testing was focussed on assessing the accuracy of flow measurement.

Incorrect orientation

The general recommendation in the manufacturers' instructions for all meter types was to avoid having the flow meter oriented vertically pointing either up or down. Amongst reasons given for this was the possibility of the entrapment of dirt or air in the flow meter body. The 'correct' orientation for general tests was with the meters at 45° to the horizontal so these tests were carried out with one meter of each pair installed with the flow meter pointing upwards and the second flow meter pointing downwards.

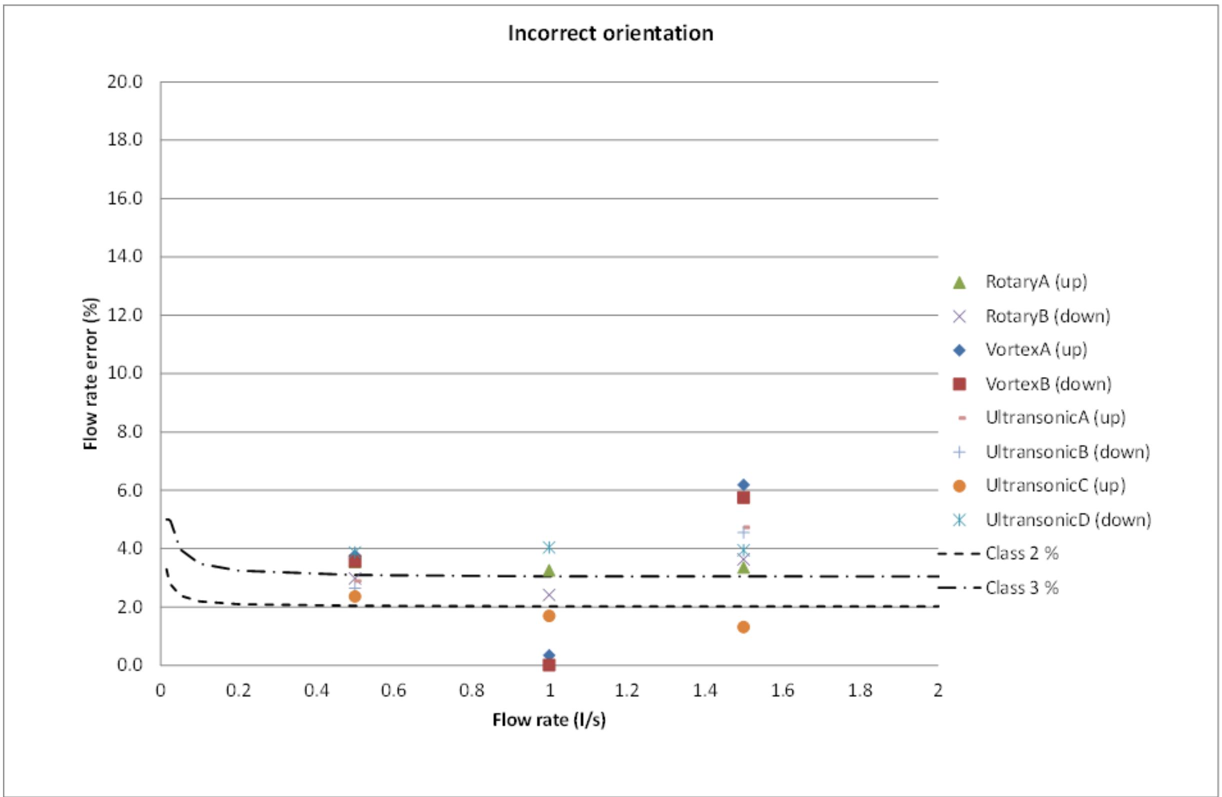


Figure 18: Flow rate error incorrect orientation

Figure 18 shows the flow rate error for the eight new DN25 meters with incorrect orientation at three different flow rates. At 0.5 and 1.0 l/s the flow rate error is comparable to the flow rate error for a correct installation (Figure 12) but the error shows an increase at 1.5 l/s, particularly for the Vortex type meters. This is at the high end of the recommended flow range of this heat meter dimension and it would be interesting to carry out further testing at this range to ascertain whether this error is characteristic of performance at this flow rate with incorrect orientation for this meter type.

Air entrainment within flow

The test rig was set up to generate a range of air entrainment rates within the fluid flow. Both samples of each meter type were installed according to the manufacturers' instructions with a range of air entrainment rates. The rig was set up to deliver two air entrainment rates 0.4 and 1.0 l/min which translated into air volume flow rates of between 0.5 and 3.5% of total flow (see Table 12). No numerical data on air entrainment in real systems could be identified but typical centrifugal pumps can only handle air entrainment levels of up to 5%. Note that under normal circumstances a conventional centrifugal pump would be expected to show a 10% reduction in capacity with 2% air entrainment and more than 40% reduction in capacity with 4% air entrainment (ITT Industries, 2002). These results are shown in Figure 19 which displays the flow rate error plotted against level of air entrainment. Both types of ultrasonic heat meters either recorded no flow or a highly erratic flow with air entrainment.

Nominal water flow rate l/s	Air flow rate l/min	Air entrainment %
0.5	0.1	0.33
0.5	1.0	3.33
1	0.4	0.67
1.5	0.4	0.44
1.5	1.0	1.11

Table 12: Air entrainment rates tested

The meters were then installed incorrectly as per 5.2.1 above but with the addition of air entrainment. Figure 20 shows the flow rate error plotted against level of air entrainment with one meter of each pair orientated pointing downwards and the other meter pointing upwards. The two ultrasonic heat meter types again either recorded no flow or a highly erratic flow. The outlier data point in Figure 20 is most probably due to experimental error.

In both Figure 19 and Figure 20 the flow errors are generally of the same order of magnitude as those recorded when the meters were correctly installed, with a trend for the magnitude of the over reading to increase for the Vortex type meters as the flow rate increases.

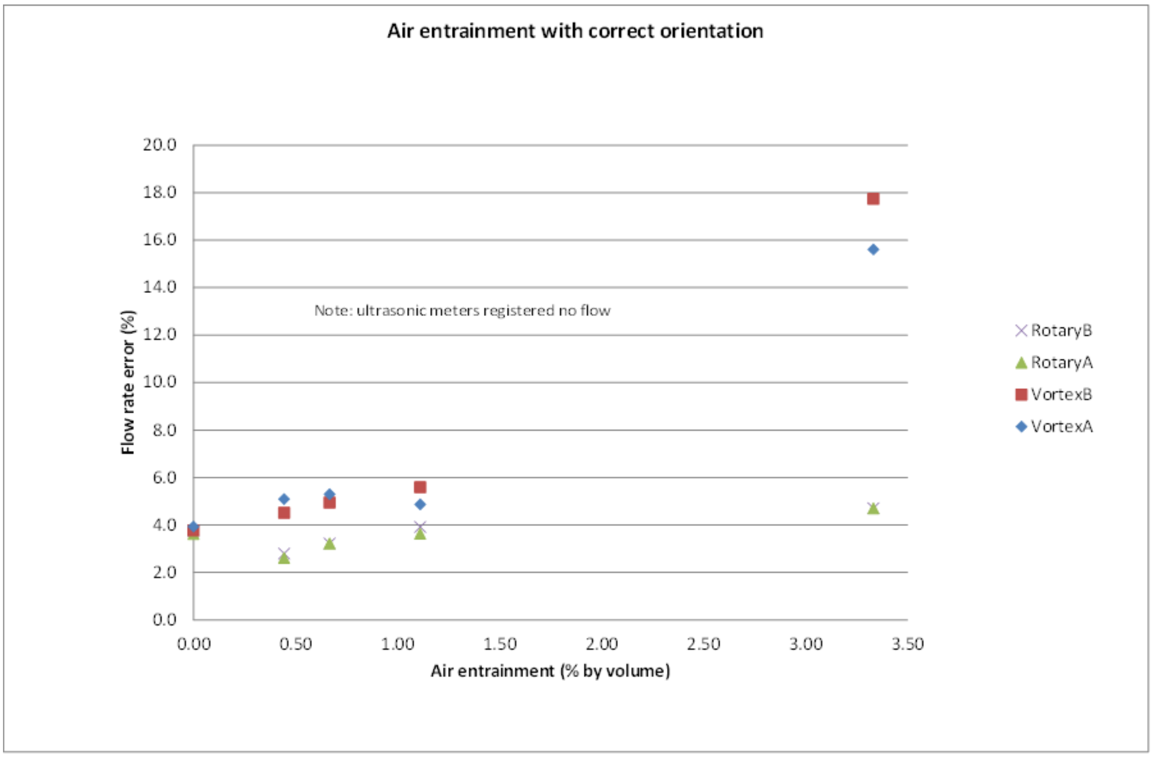


Figure 19: Air entrainment with correct orientation (ultrasonic registered no flow)

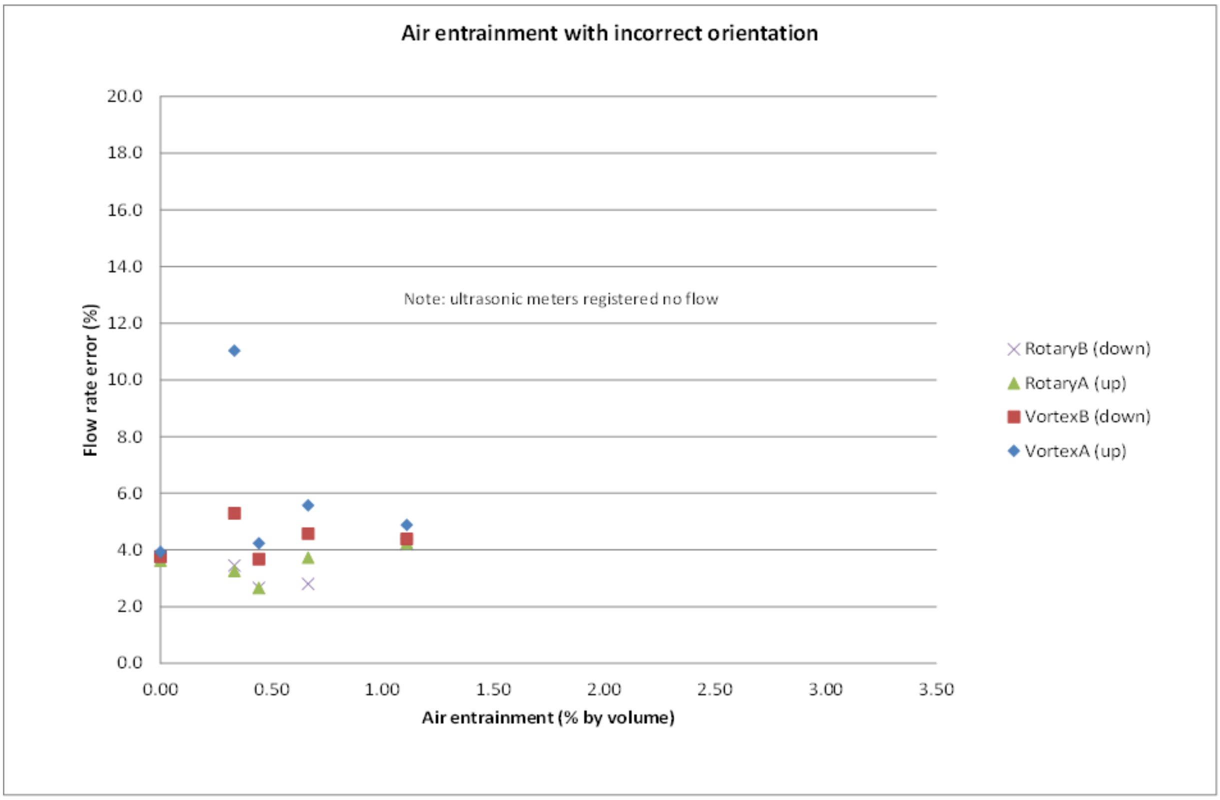


Figure 20: Air entrainment with incorrect orientation (ultrasonic registered no flow)

Close proximity to bends

One heat meter of each DN25 pair was installed with two 90° bends installed upstream. Each meter was tested correctly orientated, facing downwards and facing upwards. The flow rate errors are shown in Figure 21. For comparison the results from the MID test at 1.0 l/s (without upstream bends) have also been plotted. The comparison is highlighted in Figure 23 where it can be seen that it is in only one case (Ultrasonic C) that the installation errors have a significant effect (up to +4%) on the flow measurement, whereas in the other three cases the various errors generate small fluctuations (<±0.5%) around the original calibration test error. The figure does indicate that the ultrasonic type meters are slightly more sensitive to proximity to bends than the other two meter types.

It is appropriate to point out that this should represent a worst case scenario with both bends installed directly adjacent to the meter and hence other similar installations should not generate higher errors.

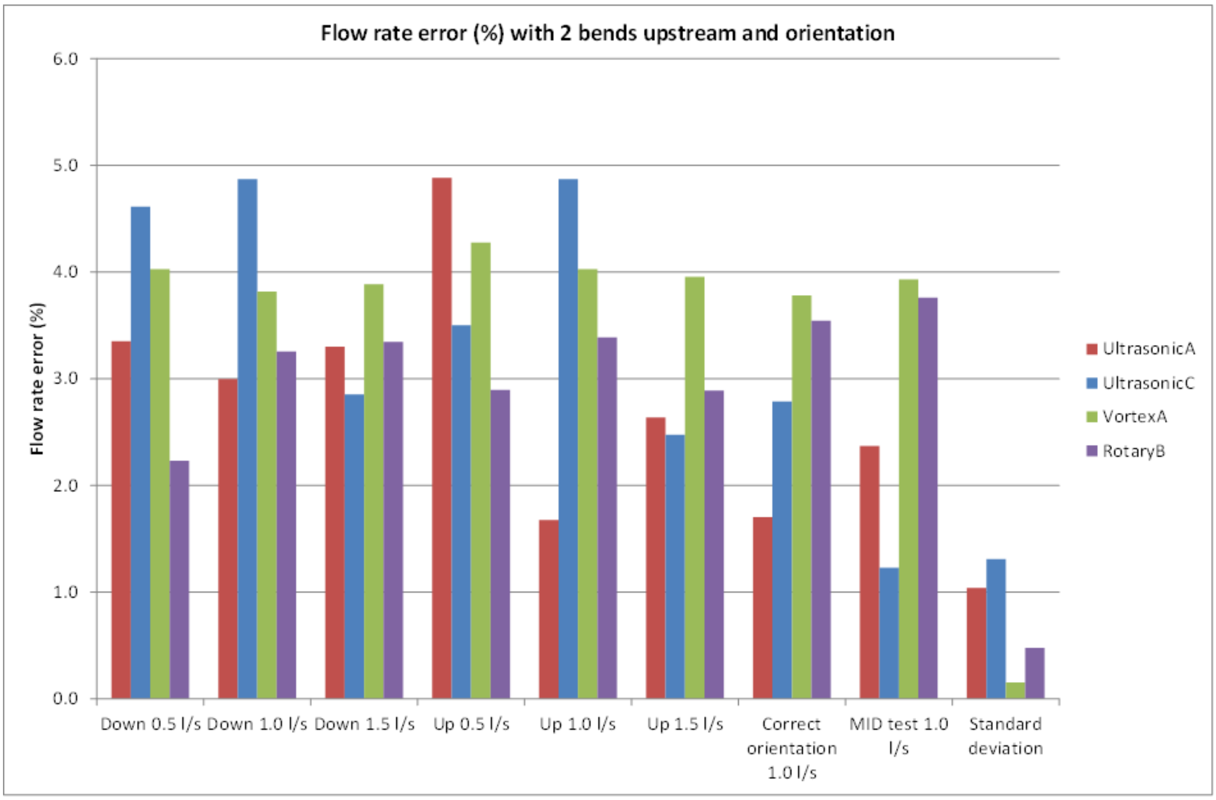


Figure 21: Flow rate error with 2 bends upstream

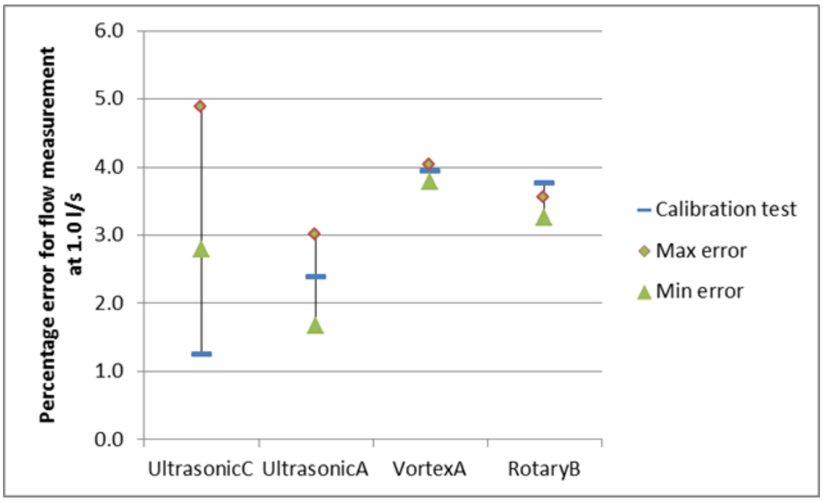


Figure 22: Flow rate error comparison at 1.0 l/s

Close proximity to pump

Each pair of heat meter samples was tested with one meter installed in the pipe line immediately before the pump and the other after the pump, with no air, air injected at 4 l/min and with 2 bends upstream of the meters.

Figure 23 shows that while in most instances the error for the combination of installation effects was of the order of 2%, the combination of air and the meter installation just before the pump had a significant effect on the vortex meter, with errors between 5 and 9%. As noted before, the ultrasonic meters ceased to operate with air in the flow.

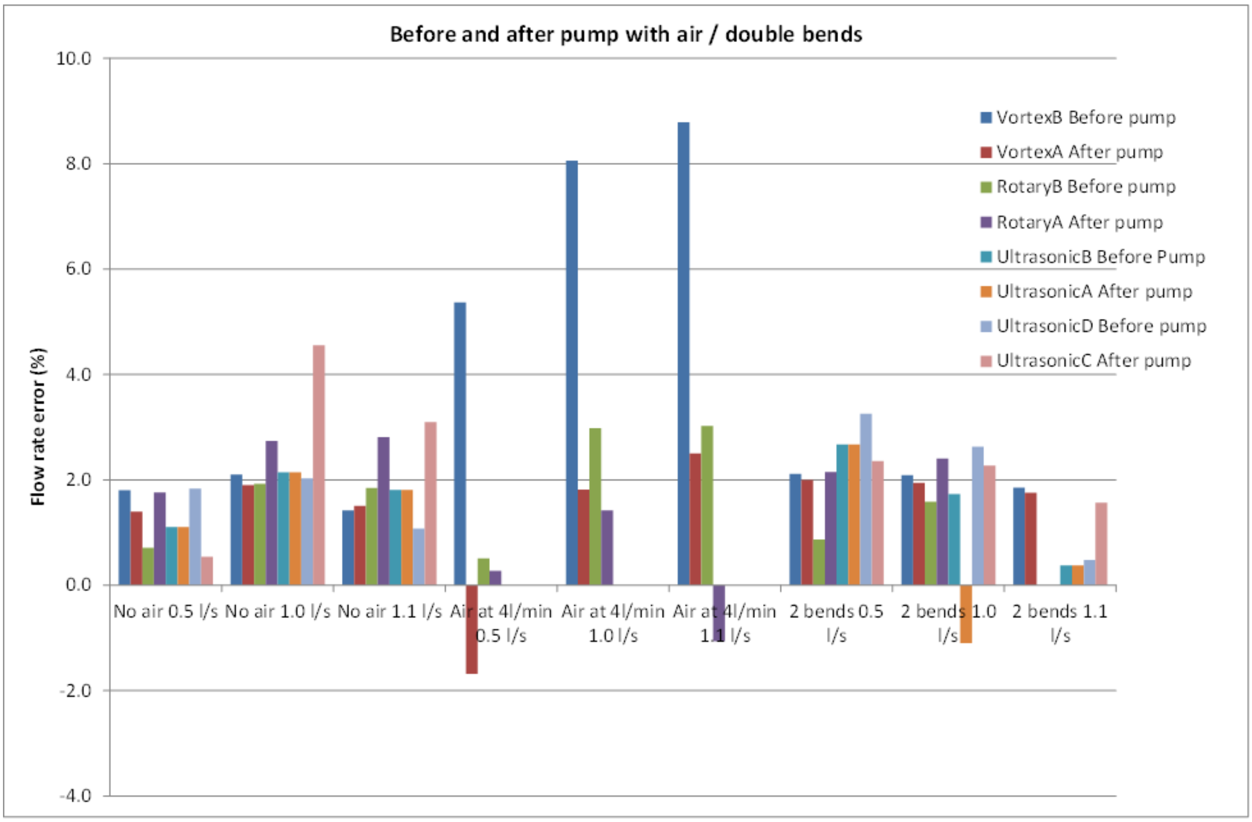


Figure 23: Flow rate error with heat meter in close proximity to pump

Testing of effect of changes in fluid (glycol antifreeze protection)

One sample of each type of DN25 heat meter was tested at two concentrations of glycol (10% and 30%) and two flow rates (0.5 and 1.0 l/s). The circulating flow temperature was 40°C in all tests and the heat meter temperature sensors were maintained at 40°C and 45°C for a 5°C temperature difference.

The glycol was a proprietary product, Sentinel R600, which is marketed and widely used in air source heat pump installations. The manufacturer states that the product is a solution of inorganic and organic corrosion and scale inhibitors in propylene glycol. The manufacturer's data sheet provides dilution information for protection to -10°C and -30°C.

The predicted errors in heat meter energy readings for an uncorrected meter are shown below in Table 13. At the fluid temperature used in the tests (40°C) the predicted energy errors are +0.7% and +3.9% for 10% and 30% glycol respectively. In other words, a heat meter calibrated for water will over read if glycol is present and similarly, a heat meter calibrated for glycol will under read if the concentration of glycol decreases over time.

Table 14 shows a comparison of the actual (measured) and predicted energy errors for the range of tests carried out. There is a very good correlation between the actual and the predicted energy in most cases. This implies that an incorrectly configured meter can be corrected through the application of a calculated factor to the measured energy.

At 30C	0% Glycol	10% Glycol	30% Glycol
Sp ht cap kJ/litre.K @30C	4.16	4.11	3.97
Energy error if uncorrected (%)	0.00	1.15	4.59

At 40C	0% Glycol	10% Glycol	30% Glycol
Sp ht cap kJ/litre.K @40C	4.14	4.11	3.98
Energy error if uncorrected (%)	0.00	0.70	3.90

At 70C	0% Glycol	10% Glycol	30% Glycol
Sp ht cap kJ/litre.K @70C	4.10	4.10	3.99
Energy error if uncorrected (%)	0.00	0.00	2.70

Table 13: Predicted specific heat capacity and energy error (%)

Figure 25 shows that the error increases for uncorrected meters as the percentage glycol increases, as would be expected from the calculations.

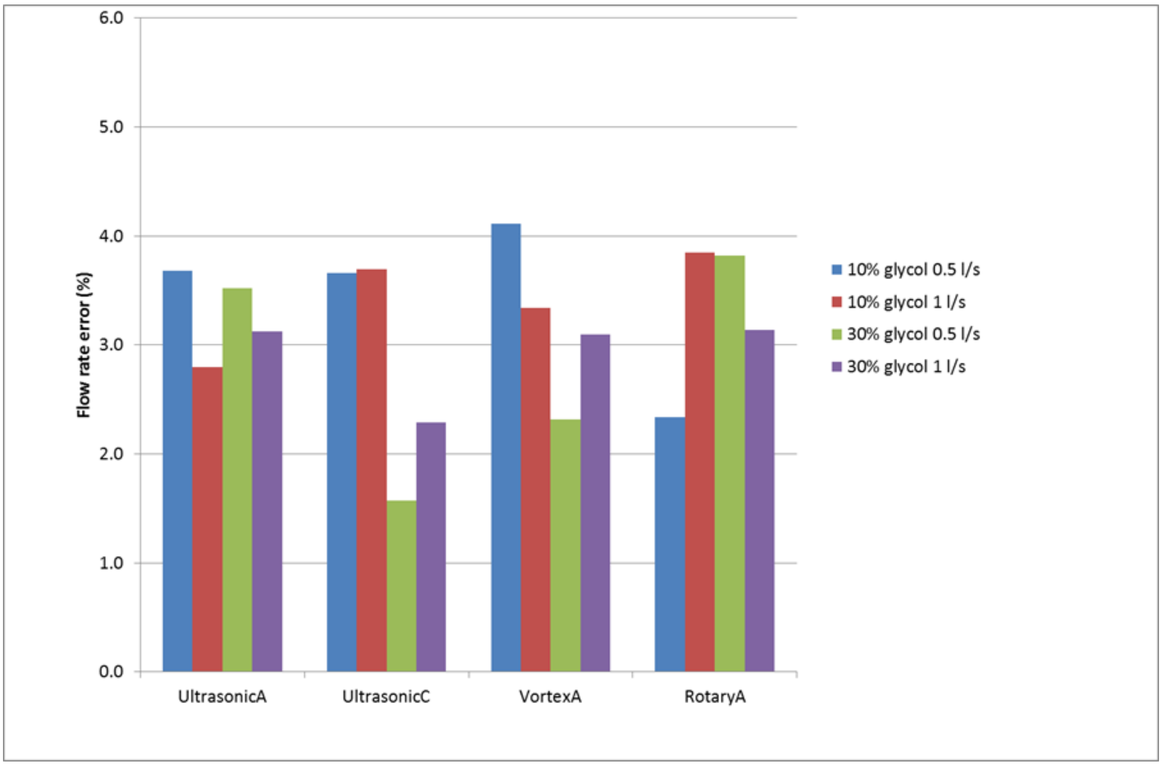


Figure 24: DN25 heat meter flow rate error with 10% and 30% glycol (uncorrected heat meters)

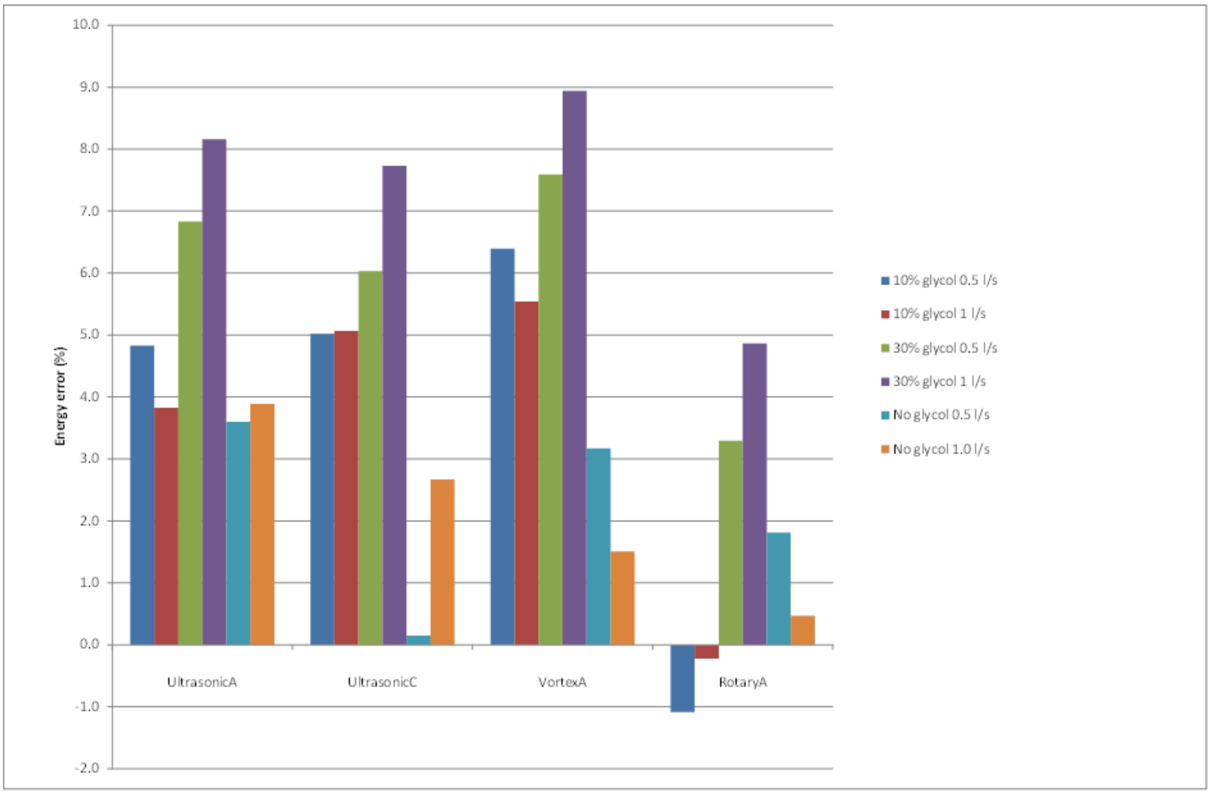


Figure 25: DN25 heat meter energy error with 10% and 30% glycol (uncorrected heat meters)

		Measured	Expected	Measured	Expected
	No glycol 0.5 l/s	10% glycol 0.5 l/s	10% glycol 0.5 l/s	30% glycol 0.5 l/s	30% glycol 0.5 l/s
UltrasonicA	3.6	4.83	4.3	6.83	7.5
UltrasonicC	0.15	5.02	0.85	6.03	4.05
VortexA	3.17	6.40	3.87	7.59	7.07
RotaryA	1.81	-1.08	2.51	3.29	5.71
	No glycol 1.0 l/s	10% glycol 1 l/s	10% glycol 1 l/s	30% glycol 1 l/s	30% glycol 1 l/s
UltrasonicA	3.89	3.83	4.59	8.16	7.79
UltrasonicC	2.67	5.06	3.37	7.73	6.57
VortexA	1.51	5.54	2.21	8.94	5.41
RotaryA	0.47	-0.22	1.17	4.87	4.37

Table 14: Comparison of measured and expected percentage errors for energy metering with different glycol concentration and flow rates

Calibration testing - temperature measurement

The calibration tests were undertaken with the heat meter temperature sensors installed in water temperature baths to very accurately simulate a heat generator with a constant 5K inlet to outlet temperature difference. The DN25 meters were in addition tested with a 3K and 10K temperature difference. The errors between the corresponding water bath temperature (measured with a calibrated laboratory quartz temperature measuring system) and heat meter indicated temperatures and the errors in temperature difference are shown in Table 15 and Table 16.

The tables show that errors in absolute temperature for individual temperature sensors were relatively high (highest error 0.63°C), but that the errors in temperature difference (dT) were very low (mostly below 0.05K). There was also no discernible difference between meter types and age of meter. This confirms that manufacturers select matched pairs of temperature sensors and that the accuracy of the PT500 sensors used by the majority of manufacturers is of a similar grade.

An important consequence of the above finding is that although temperature sensors are accurate for the evaluation of temperature difference for energy calculation, the accuracy of absolute temperature measurement is relatively poor. This does not affect true heat metering applications but may be important where heat meters are being used to gather data in field trails or in laboratory applications.

New DN25 meters - mean of 8 tests	Meter 1	Meter 2	Meter 3	Meter 4	Meter 5	Meter 6	Meter 7	Meter 8
Low sensor error	0.23	0.18	0.56	0.49	0.49	0.59	-0.06	-0.06
High sensor error	0.24	0.20	0.44	0.42	0.52	0.63	-0.12	-0.10
dT error	0.01	0.03	-0.12	-0.07	0.04	0.04	-0.06	-0.04

Table 15: Temperature sensor errors for new DN25 meters (2 samples of 4 meter types)

Old DN20 meters - mean of 6 tests	Meter 1	Meter 2	Meter 3	Meter 4	Meter 5	Meter 6
Low sensor error	0.37	0.39	0.19	0.40	0.17	0.29
High sensor error	0.31	0.41	0.20	0.41	0.19	0.31
dT error	-0.06	0.02	0.01	0.01	0.01	0.03

Table 16: Temperature sensor errors for old DN25 heat meters (6 vortex meters)

Testing of different and incorrect temperature sensor mountings

The effect of alternative temperature sensor mounting was tested for a range of pocket, strap-on and surface sensor configurations undertaken with a single sample of each DN25 heat meter type.

'Binder's refer to the installation of the temperature sensors installed in a self-sealing test plug which allows direct contact with the water flow and with each sensor facing the direction of water flow.

Paste refers to the application of a proprietary thermal heat transfer paste used for mounting heat sinks to electronic components (RS Components Heat Sink Compound).

All of the tests were undertaken with a 12kW electric boiler as heat source. For test lab practicality reasons two 6 kW boilers were used in parallel to provide 12 kW. The test rig installation is shown in Figure 26. The use of electric boilers also allowed the supplied heat energy to be very accurately evaluated using an electricity meter in the boiler electricity supply, in addition to the inline reference flow meter and temperature sensors. This provided additional confidence in the reference energy measurement.

The tests were carried out in both steady state (fixed flow and fixed temperature difference) and transient mode (fixed flow and variable temperature difference, and variable flow and fixed temperature difference).

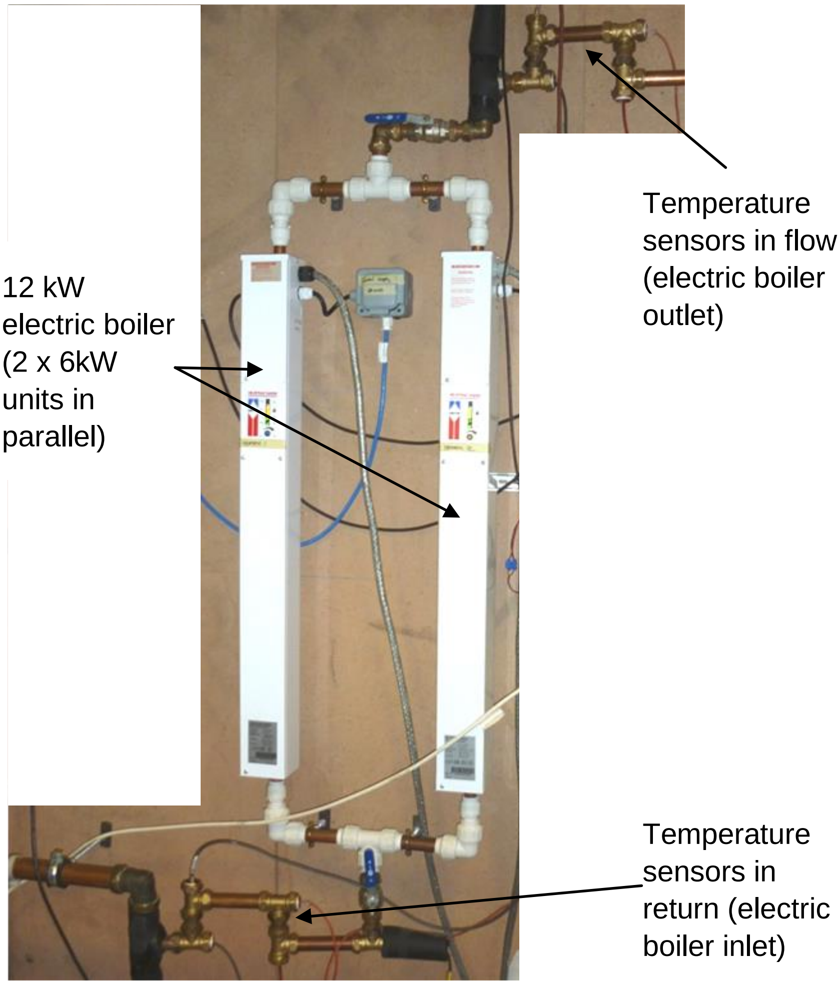


Figure 26: Electric boiler and temperature sensor mounting test location

Mounting of sensors in pockets

The manufacturer supplied pockets were mounted in the branch section of a standard 28mm pipe tee. To accommodate the length of each pocket the branch was extended by an appropriate amount, see Figure 27. To avoid the risk of trapped air around the pockets causing measurement errors the pockets were also installed facing downwards. In a permanent long term installation it is important also to prevent the collection and built up of dirt around the pocket which may impede heat transfer to the sensor so the optimal orientation would be approximately 90° to the pipe axis vertical plane. The tests were undertaken with and without external thermal insulation and with and without thermal paste, see Figure 27.

Sensor smeared with thermal paste prior to insertion into pocket

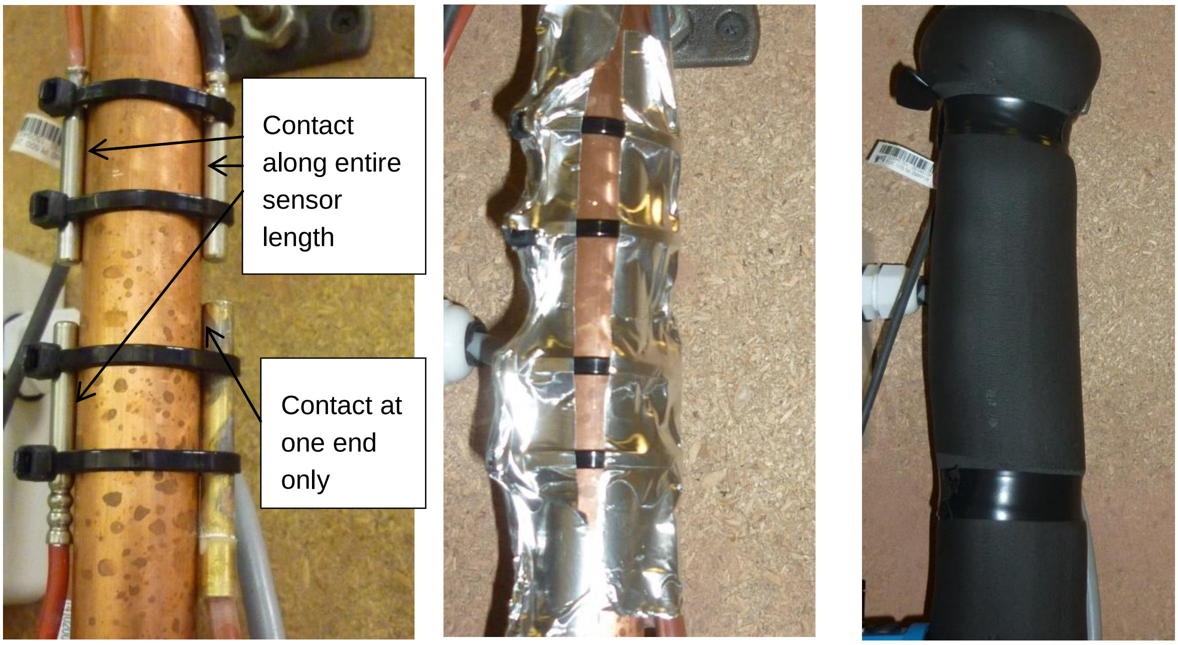
Figure 27: Sensors mounted in pockets (insulated and uninsulated, with and without paste)

Strap-on and surface sensors

Strap-on sensors means standard sensors (intended for use in pockets) that have been attached to the pipe wall. This might occur in practice if it is too difficult or impractical to fit a pocket or where an installer chooses to this to reduce installation time.

It is fairly typical for temperature sensors to be attached to the outside of pipes in control system installations. In this case it is usual for the sensor to be attached to the pipe wall using two self-locking plastic cable ties and to cover over with pre-formed flexible closed cell pipe insulation. This method relies on the both the sensor and pipe wall being true and straight and for the correct size of cable tie to be used and for it to be pulled sufficiently tight. This requires a degree of subjective judgement by the installer and is therefore potentially subject to variation.

It was observed that the sensors supplied with the rotary heat meter had a constant diameter and the plastic sleeve covering the cable entry mean that the sensor could not maintain continuous contact with the pipe. The other heat meters had sensors with crimped ends around the cable entry which allowed continuous contact between the sensor and pipe (assuming the pipe was straight and true), see Figure 28.



Standard sensors strapped on to pipe surface with two cable ties

Tape covering to reduce convective heat transfer

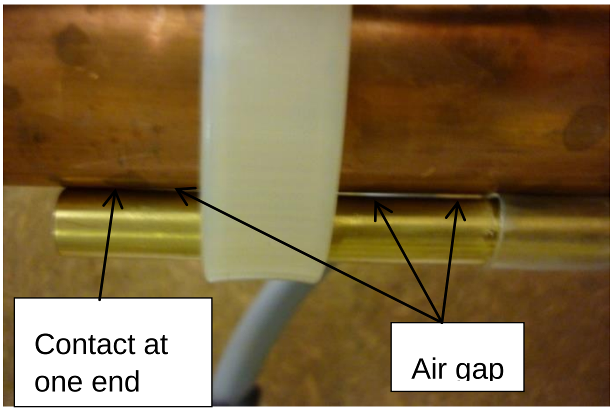
Closed cell pre-formed pipe insulation with taped joint

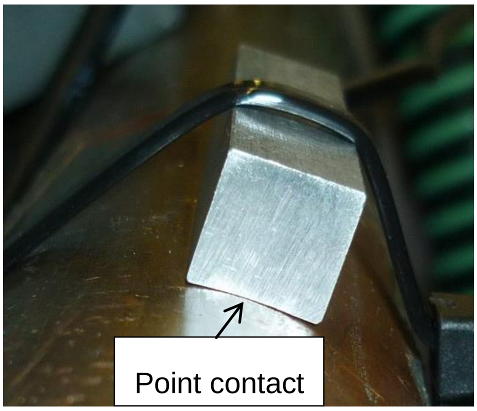
Figure 28: Strap-on sensors

Surface temperature sensors means temperature sensors sold as intended for pipe surface mounting. Two proprietary types were purchased from two heat meter suppliers, see Figure 29. One appeared to a standard sensor (Type A) but supplied with a wider than normal plastic cable tie (one per sensor), and the other was encapsulated inside a short section of square section aluminium block with one face curved to fit the pipe surface (Type B). However, in practice the radius of the curved face meant that it would only provide point contact on the majority of pipe sizes. This sensor was supplied in one size only and no reference was made to the pipe size in the supplier's technical data.

The supplier of Type A surface sensor specifically stated in the supplied instructions that thermal paste should be used between the sensor and pipe and that it should be covered with insulation.

The use of thermal paste (RS Components Heat Sink Compound) filled some of the air gap between the sensors and the pipe wall. However, it is clear that there is potentially a high level of variability depending on the pipe diameter and thickness of applied thermal paste. It was also found that in practice when mounting the sensors and tightening the cable ties the sensor could swivel and wipe away some of the thermal paste.

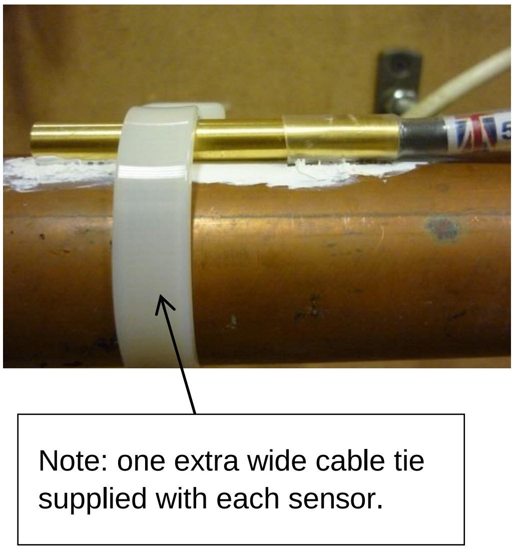




Plastic sleeve on cable entry end of sensor type A prevents continuous contact

Pre-shaped aluminium sensor type B is a 'universal' size so does not fit all pipe sizes

Figure 29: Surface temperature sensors without heat transfer paste



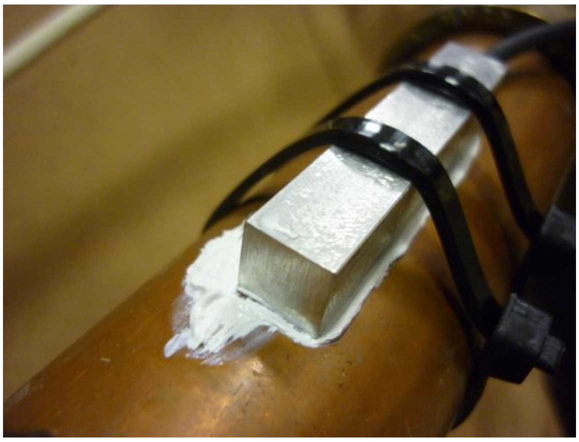


Figure 30: Surface temperature sensors with thermal paste

Mounting of sensors in ‘‘Binders’

The piping configuration was for ‘‘Binder’’ mounting is shown in Figure 31. This was designed so that each temperature sensor faces into the direction of water flow. Unless an inclined tee pipe fitting is used this necessitates a 90° change in pipe direction, as in the case here. In practice tee pipe fittings with an inclined branch are unusual and difficult to obtain in the UK so the arrangement used in the tests is likely to be the most practical installation method in the field, especially for the pipe sizes used in domestic installations. Due to the large diameter of some of the heat meter temperature sensor probes (6mm) a compression gland was used instead but this is equivalent to a ‘‘Binder’’ in all other respects except that the fitting is not self-sealing when the sensor is removed. Figure 32 shows how a standard compression tee fitting was adapted to provide an appropriately sized compression gland.

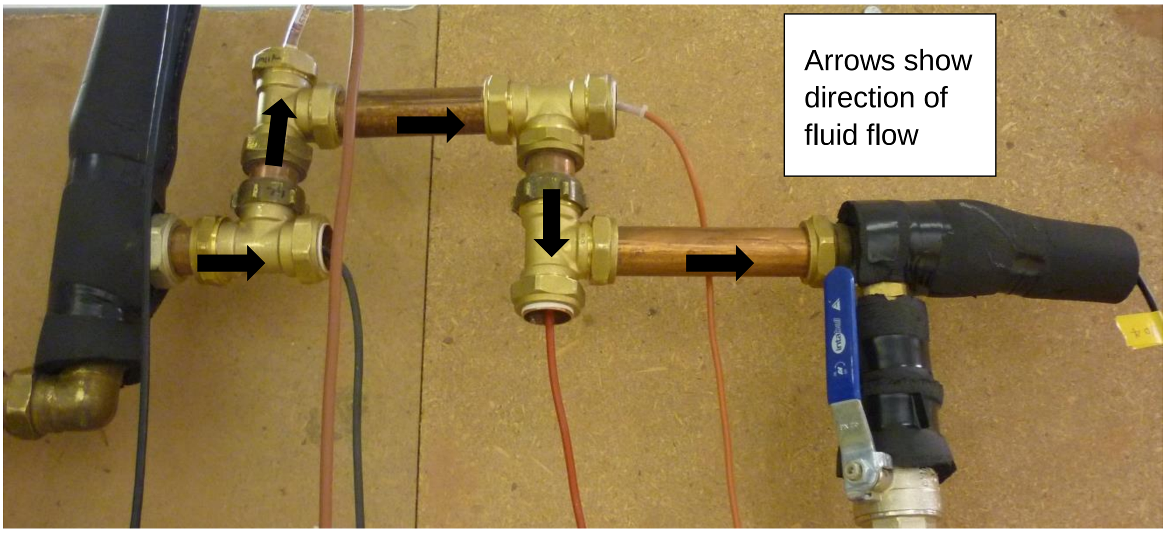


Figure 31: Piping configuration used to mount sensors in ‘‘Binders’

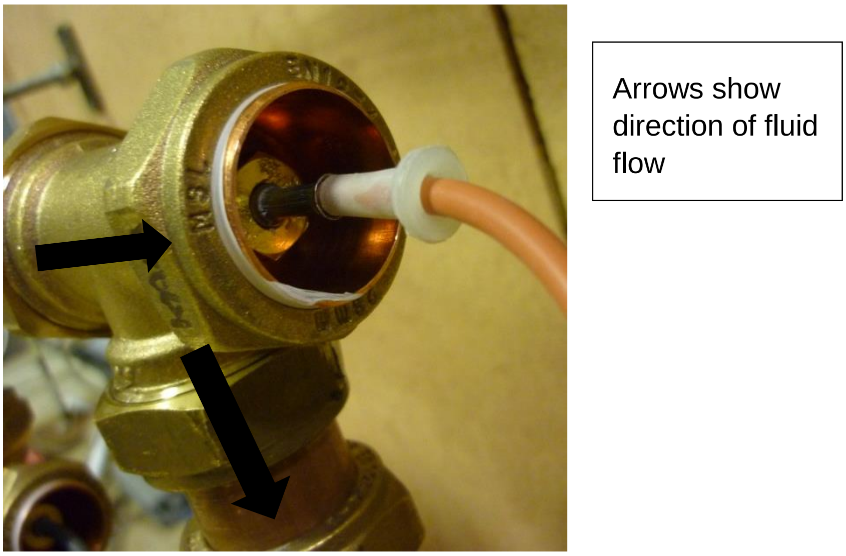


Figure 32: Adapted compression tee fitting to provide compression gland mounting of sensors

Sensor mounting test results

Errors were assessed on the basis of the error in metered energy over the duration of the test. The test duration varied with approximately 24 hours for tests with varying heat generator power and around 7 hours for tests with a constant heat generator power.

The entire temperature sensor mounting test results are shown in Figure 33. These results also display a wide variation between the different meter types and this could be due to the different physical characteristics of the temperature sensors, some of which appeared to be particularly unsuited to surface mounting.

To aid clarity the errors from the temperature sensor mounting tests with pockets and 'Binders only are shown in Figure 34 and the errors for the strap-on and surface sensors only are shown in Figure 35. Figure 34 clearly indicates that the scale of the error with different types of pockets and test plug (installations) is quite minimal between -1% and a maximum of 6%, with or without paste, and whether or not the circuit temperature is maintained constant or cycled. The maximum permissible error allowed for the MID Class 2 energy measurement varies according to the flow and temperature difference, but is of the order of 5-8%. These errors are practically of the same order as the majority of the errors recorded during the flow disturbance tests and are also of the same order as the errors recorded during the initial flow measurement control tests. Although the different meters were supplied with different dimensions of pockets with some pocket dimensions being considerable larger than the installed pipe diameter, the graph demonstrates that the insertion of the probe into the fluid flow results in an accurate measurement of the temperature difference, with insulation, paste, and the type of insertion having very little effect on the measurement.

In Figure 35, however, the scale of error is considerably larger, with a range from -60% to +35%. Whilst there are a few examples of relatively lower errors, these are randomly interspersed with measurements which are certainly unreliable and unfit for purpose. The figure does indicate that the use of strap-on and surface type sensors is a very risky procedure. These results also display a wide variation between the different meter types and this could be due to the different physical characteristics of the temperature sensors, some of which appeared to be particularly unsuited to surface mounting. Only two types of meter were tested with surface temperature sensors since these sensors were considered as proprietary to the meter supplier. The surface sensors, although ostensibly designed for installation on the pipe surface, did not demonstrate any advantage over the strapped-on standard temperature sensors supplied with the meters. The four sets of measurement on the right hand side of Figure 35 relate to measurements taken when the pair of sensors were installed differently from each other. As expected, these experiments showed the largest measurement errors.

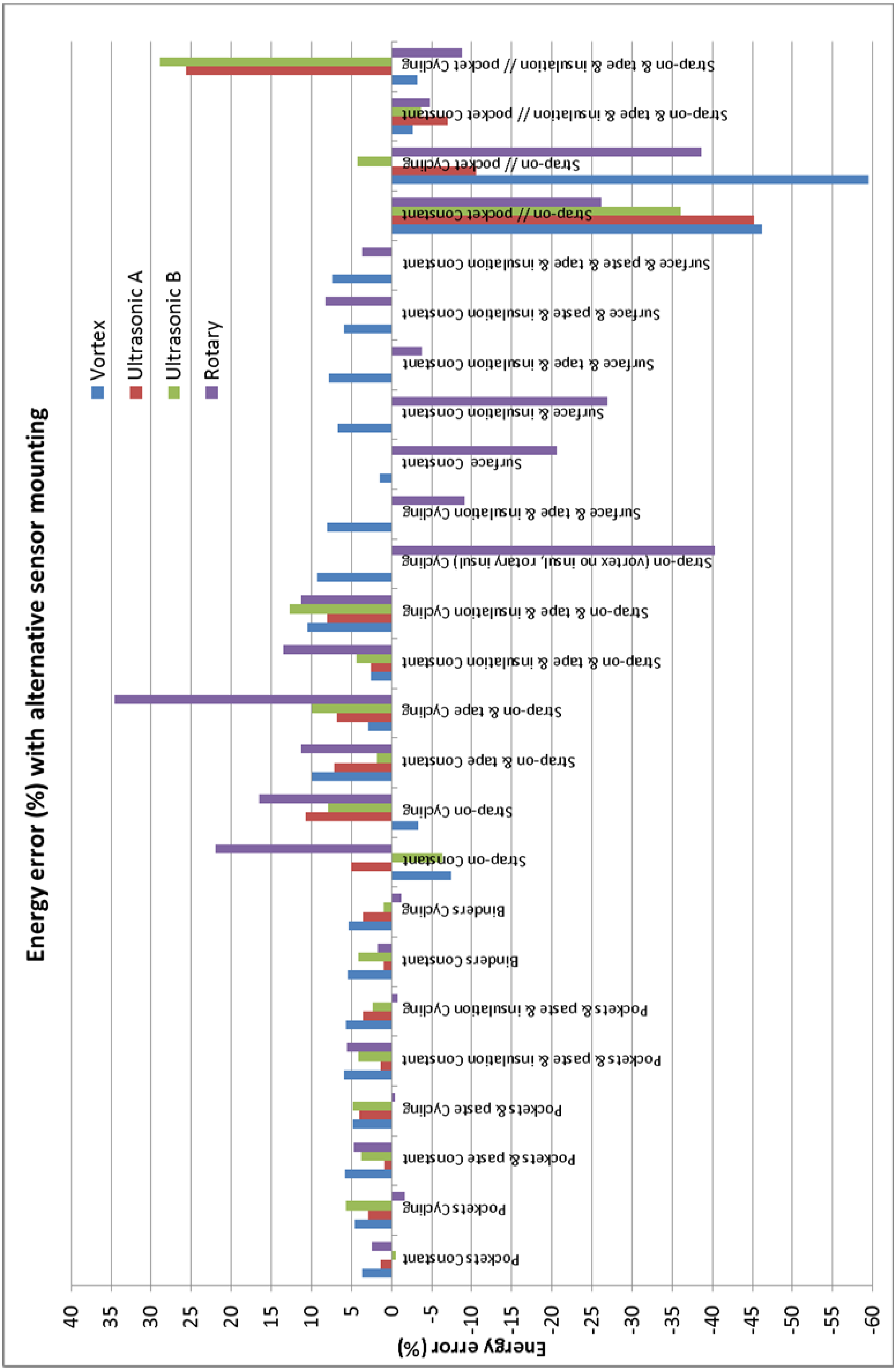


Figure 33: Energy errors from all temperature sensor mounting tests

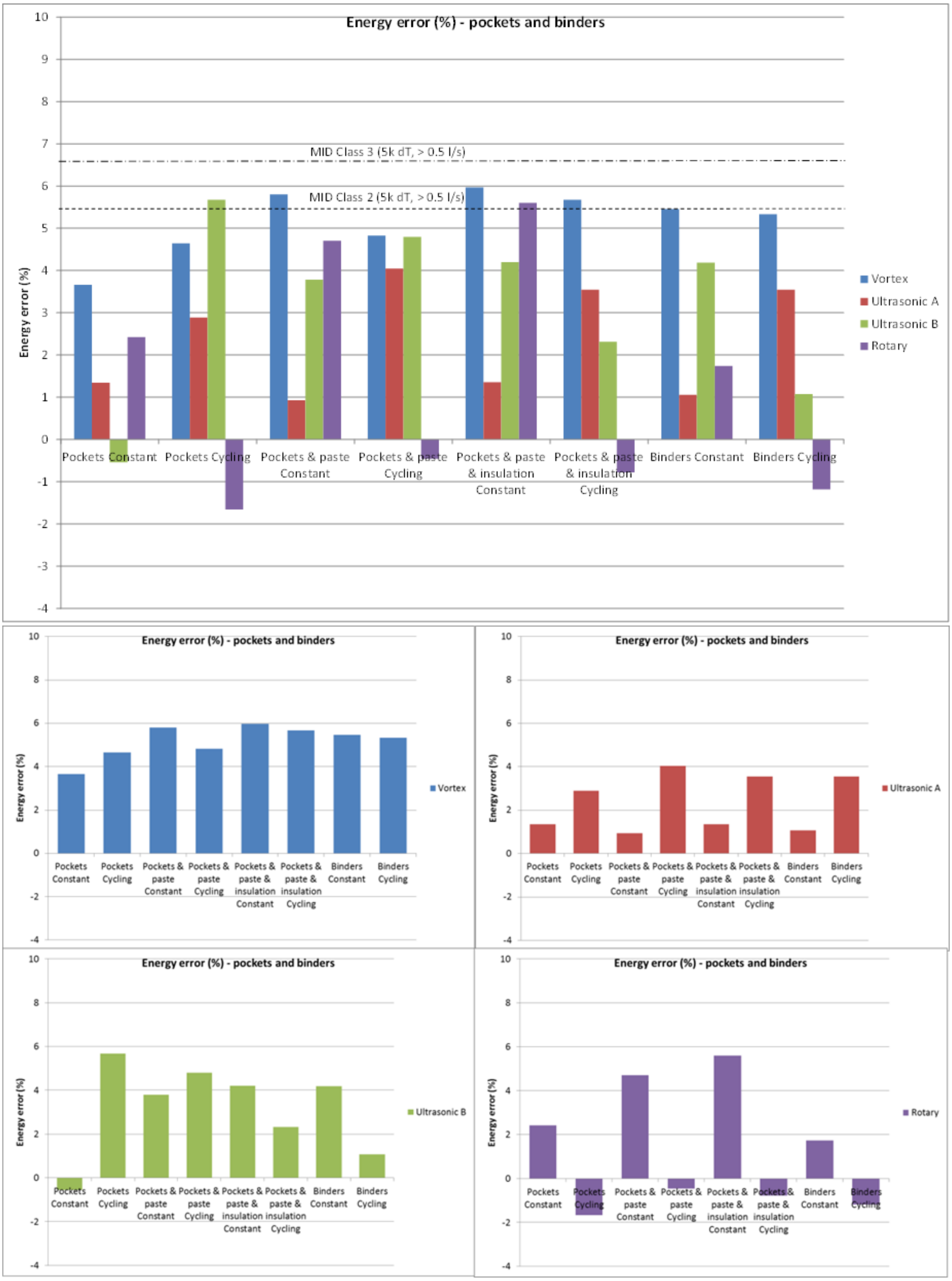


Figure 34: Energy errors from temperature sensor mounting tests with pockets and 'Binder's only

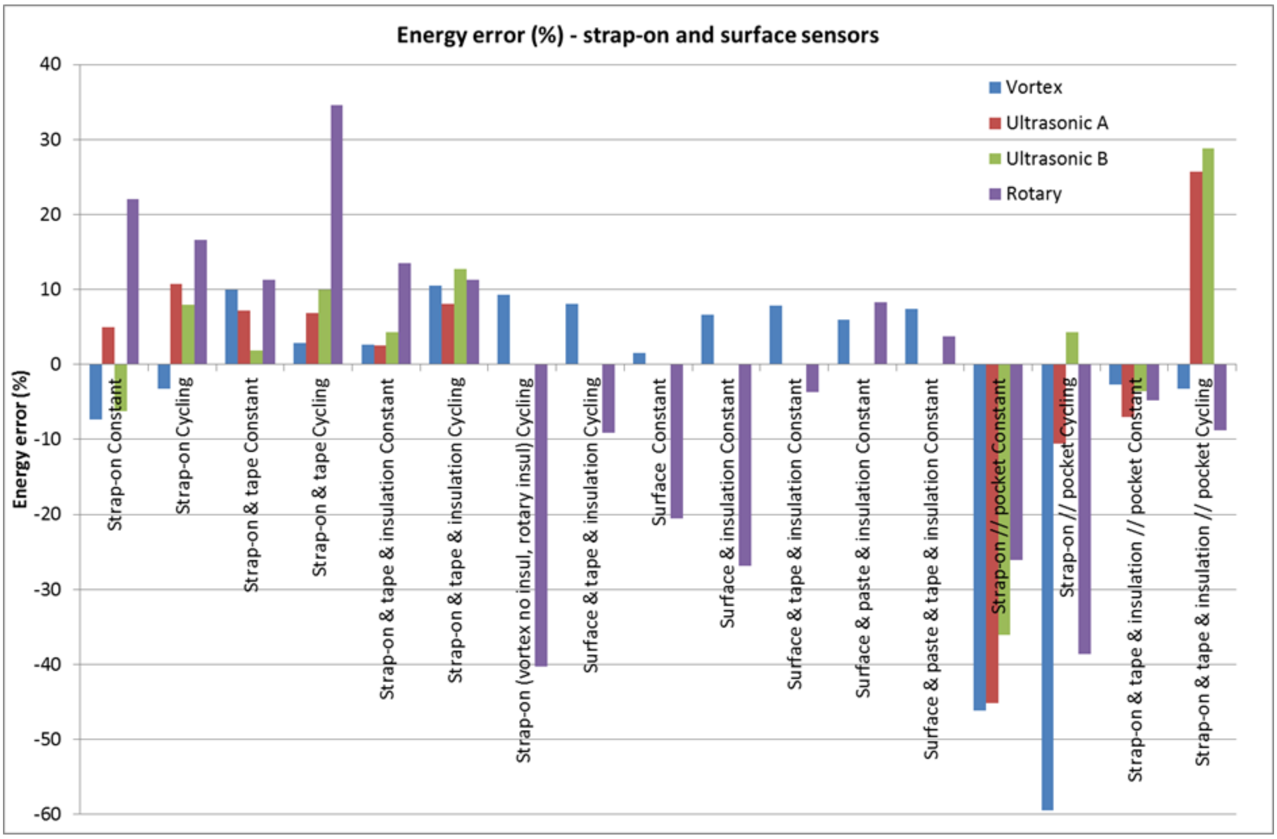


Figure 35: Energy errors from temperature sensor mounting tests with strap-on and surface sensors only

Transient operation

Whilst the majority of tests in a laboratory environment are carried out at steady state conditions, it was deemed important to simulate actual field conditions by varying the temperature and varying the fluid flow rate in the circuit and investigating what effect this had on the different meters.

Figure 37 and Figure 38 show the result of operating the laboratory test rig with a varying flow rate over twelve hours and a varying temperature respectively. In both instances the error in the energy measurement is within the limits established by MID Class 2, albeit as a borderline case for two of the meter types for the varying flow rate test.

A more practical implementation of temperature variation across the heat meters was generated by installing two different DN40 meters on the heat pump certification test rig and monitoring these meters over a series of heat pump tests. The results of these tests are shown in Figure 39 for temperature sensors in manufacturer supplied pockets and Figure 40 for strap-on and surface temperature sensors. Figure 36 shows the temperature fluctuations of one of the heat pump cycles used for these tests.

Figure 39 and Figure 40 demonstrate that the vortex type meters do not manage to remain within the MID Class 2 levels when subject to varying temperature conditions and in Figure 40 it can also be seen that the effect of the strap-on / surface sensors is to increase the error further.

Note that the difference in results between runs shown in Figure 39 are due to each run of the air source heat pump (ASHP) being different and therefore having different temperature variation dynamics.

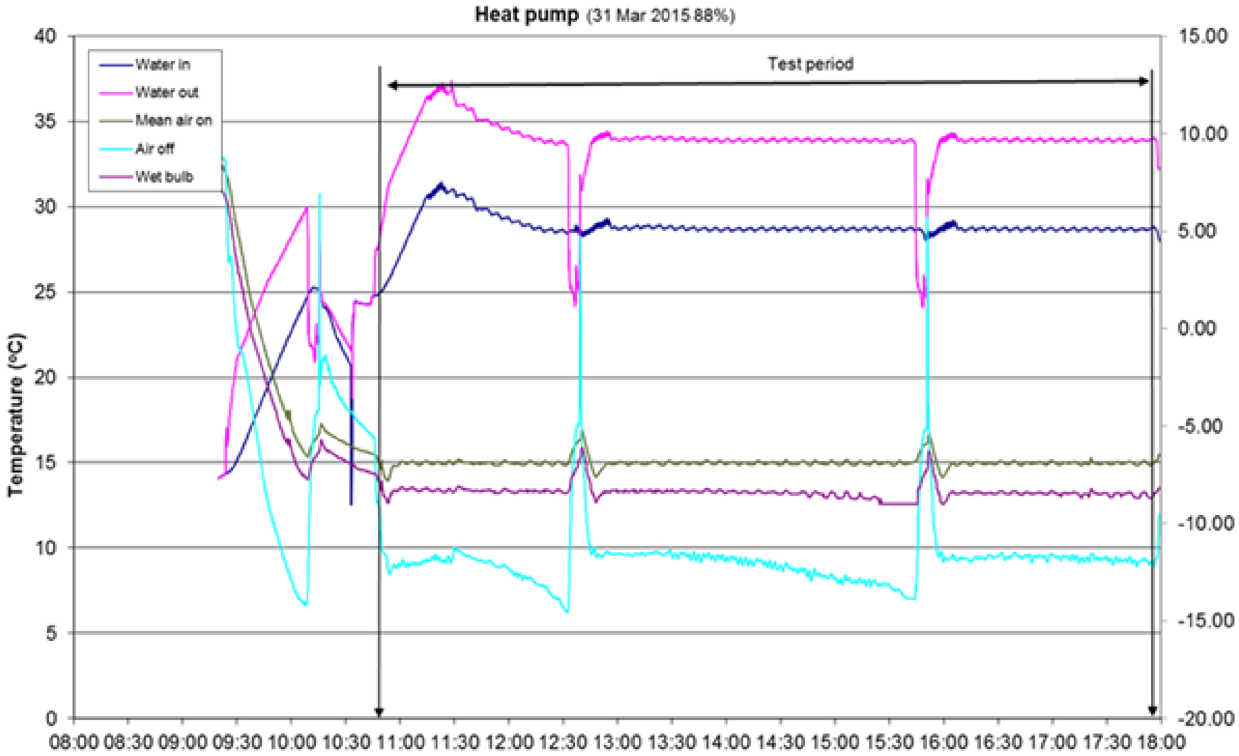


Figure 36: Typical heat pump operation test cycle

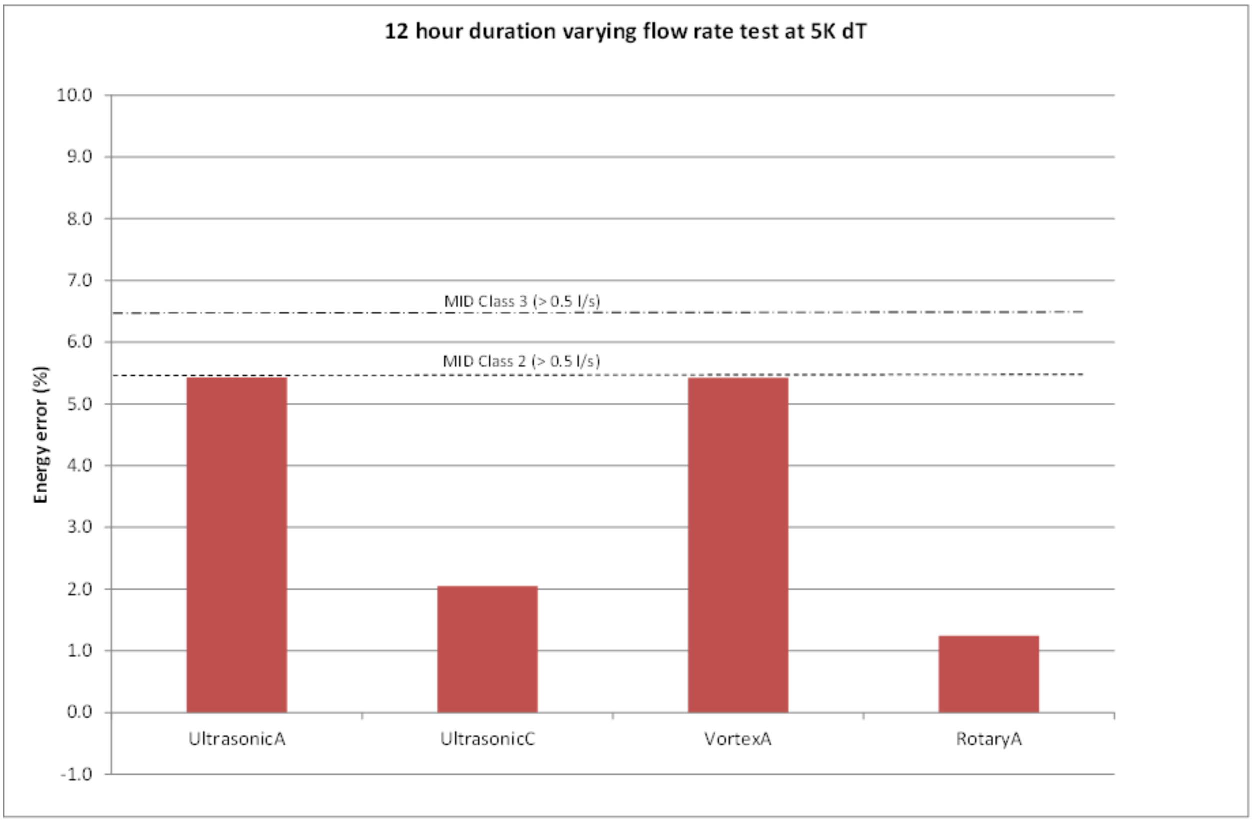


Figure 37: Energy error with varying flow rate / constant temperature – laboratory test rig

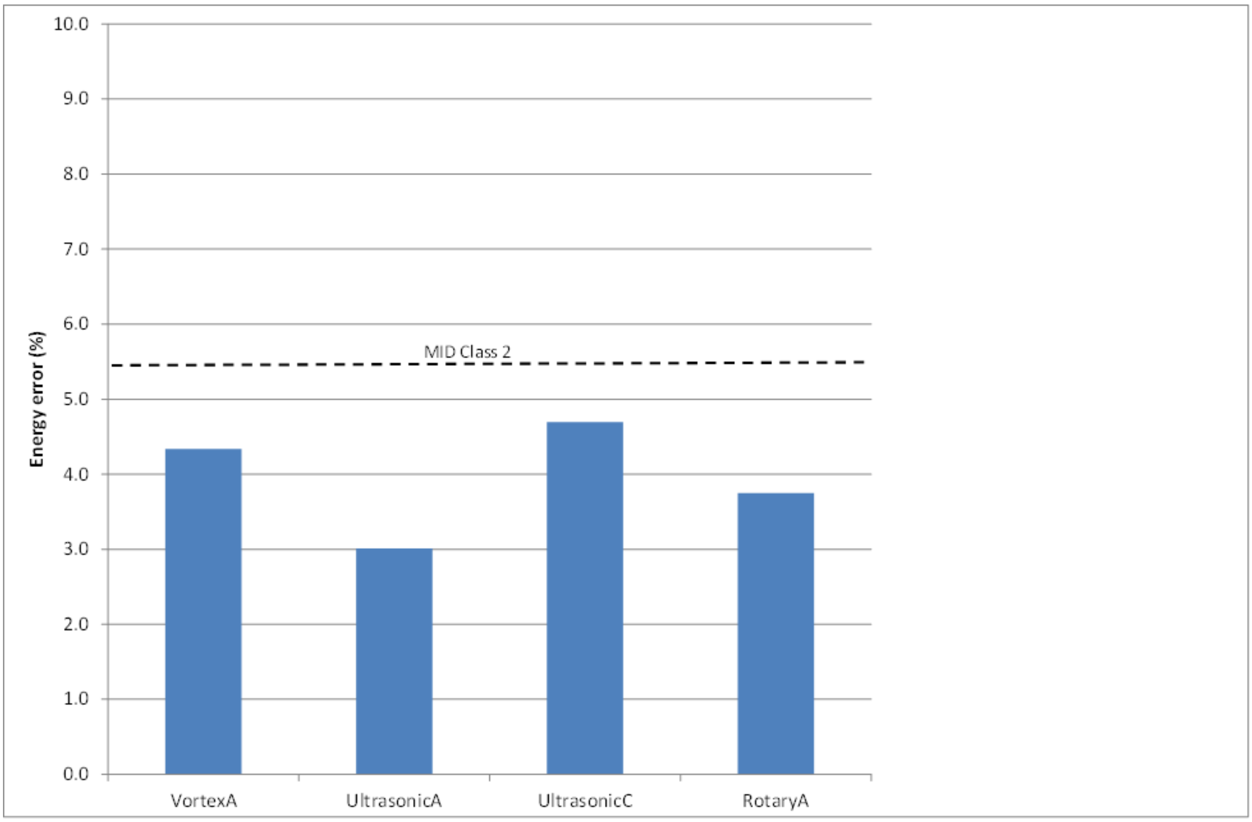


Figure 38: Error with varying temperature / constant flow rate – laboratory test rig

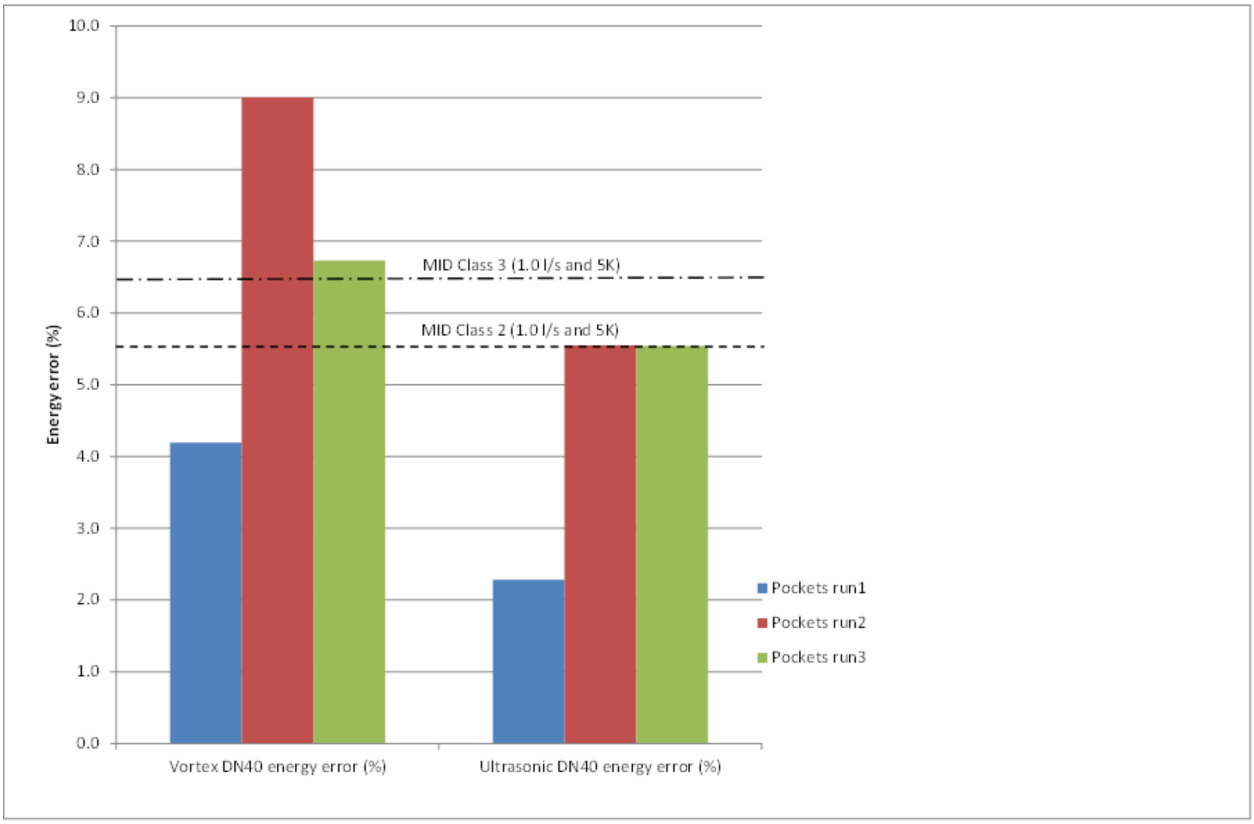


Figure 39: Error with varying temperature / constant flow rate, standard sensors – ASHP test rig

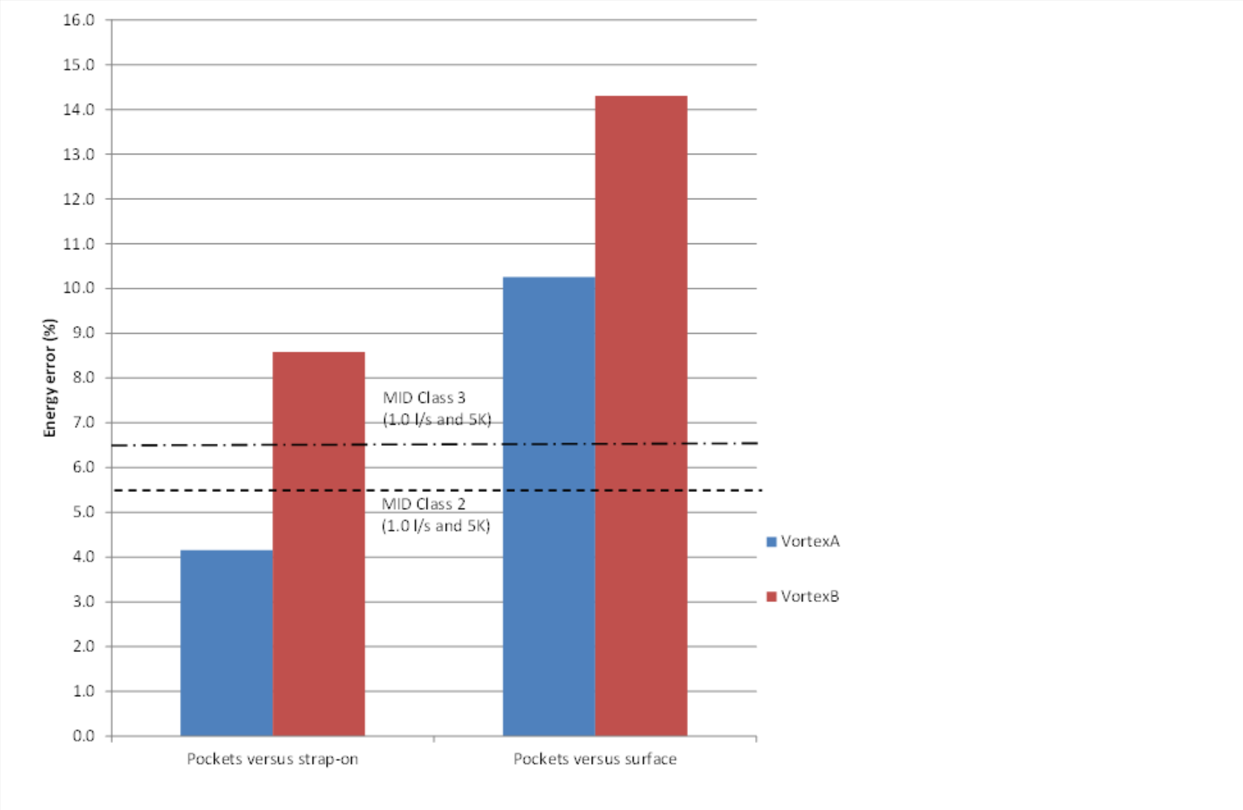


Figure 40: Error with varying temperature / constant flow rate, strap-on and surface sensors – ASHP test rig

Heat meter fluid pressure drops

Fluid pressure drop is important since the pressure drop of a heat meter installed into an existing heating system may result in a significant change (decrease) in fluid flow rate which may adversely affect the heat generator thermal efficiency and in extreme cases its operability and reliability. This is more likely to affect a heat pump than a combustion boiler.

The fluid pressure drop of each of the DN25 heat meter flow meter units (2 samples per type) was measured across a range of water flow rates using a calibrated differential digital manometer. The results for each individual heat meter are shown in Figure 41. Figure 42 compares the mean pressure drop of both samples of each meter type with the pressure drop stated in the manufacturers' product technical literature. The manufacturer of the rotary heat meter did not quote a pressure drop for the flow meter unit.

There was generally close agreement between the measured fluid pressure drops for the individual samples although there was a slightly larger discrepancy between UltrasonicA and UltrasonicB (between 10 and 20%, depending on fluid flow rate). It is noteworthy that the rotary heat meter had the highest pressure drop followed by the Vortex. Although the two types of ultrasonic heat meter both had the lowest pressure drops one was approximately twice the other. Comparison with the manufacturers' data, although for a single point only, showed reasonable agreement.

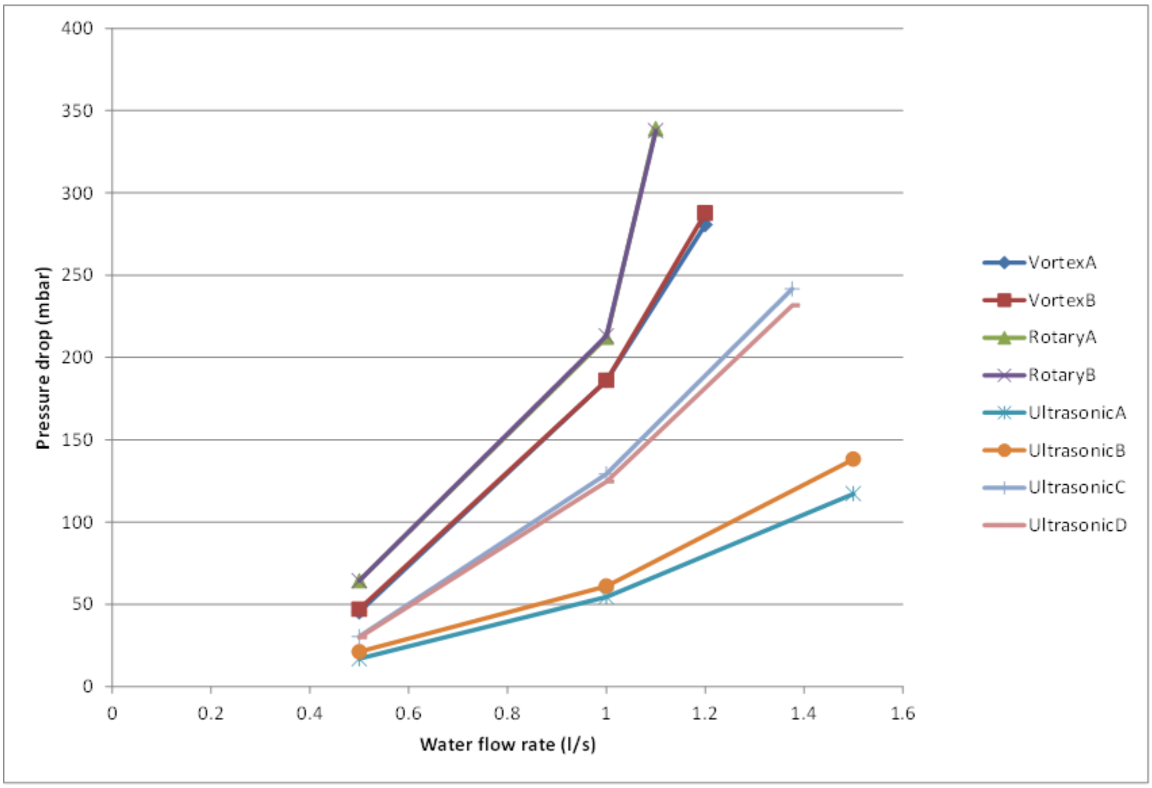


Figure 41: Heat meter pressure drops

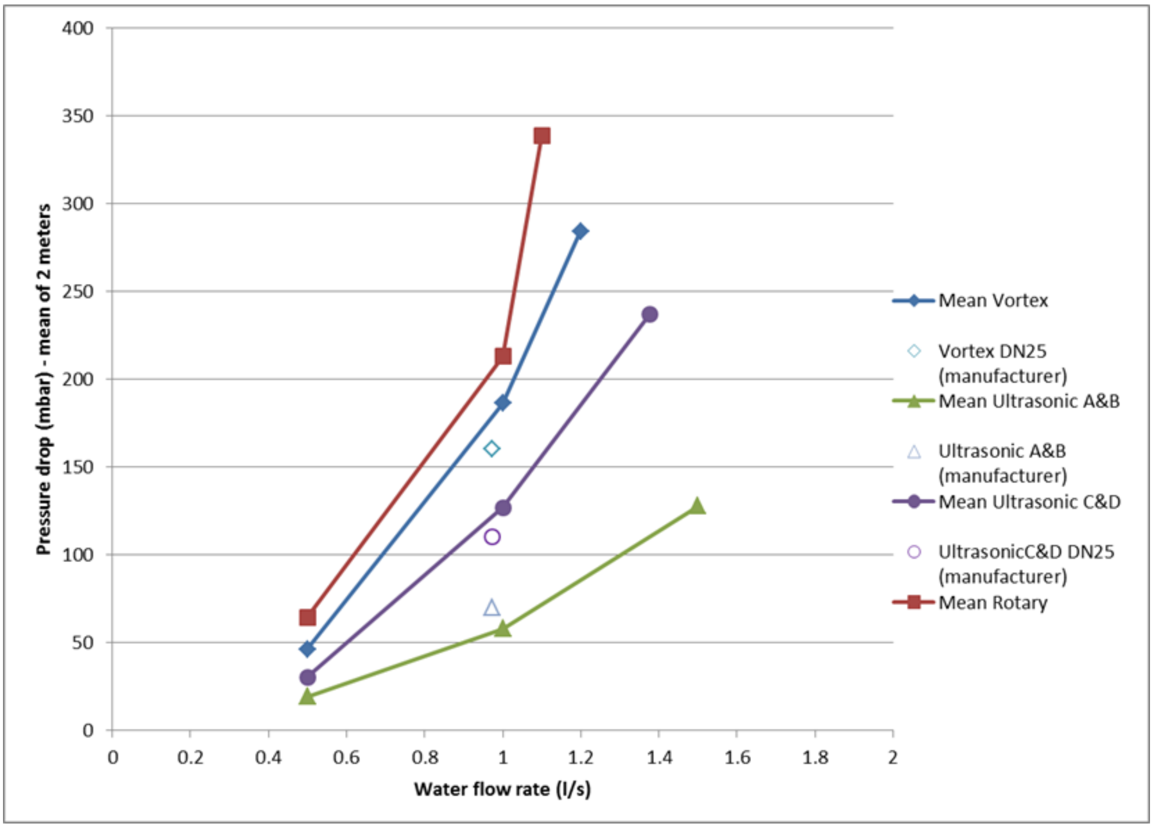


Figure 42: Mean heat meter pressure drop compared to manufacturers' data

Effect of dirt

On-going tests are being undertaken with the four types of DN25 heat meter (one vortex, two ultrasonic, and one rotary) installed in a BRE test house with an old heating system contaminated by dirt. The heating system comprises standard steel panel radiators (a mixture of single and double panel) and these have been in use for over 20 years. The original gas fired boiler was bypassed and instead an electric boiler used so that the heat energy could be accurately measured using an electric power meter. This meant that that the evaluation of the heat energy could be independent of the water flow rate in case the reference flow meter was also affected by dirt. The heat meters were installed in series with a reference electromagnetic flow meter.

An open tank was introduced into the heating system at a high level and arranged so that the circulating flow cascaded into this tank upstream of where the heat meters were installed. This was designed so that dirty water could be reintroduced into the system after being removed directly from the radiators, allow the water quality to be inspected visually and also allow continuous aeration of the circulating water to speed up internal radiator corrosion. Figure 43 shows an example of the water quality.

Figure 43: Test house installation - water quality

Experience shows that radiators tend to act as effective dirt separators by separating and retaining circulating dirt in the radiator. This effect was reduced by regularly removing contaminated water directly from individual radiators and reintroducing into the system pipework by incorporating an open tank in the main heating system circuit. This was undertaken weekly with a single radiator on a rotation basis.

The heat meter temperature sensors and the reference set of temperature sensors were installed in ‘Binder’ points so that the sensors were in direct contact with the water which eliminated any possible sensor mounting error.

Figure 44 shows the temporal variation in mean daily energy error (expressed as a percentage error compared to the electrical energy input to the electric boiler) and Figure 45 shows the temporal variation in flow rate error (expressed as a percentage error compared to the BRE reference flow meter). The energy error for the rotary heat meter has not been plotted due to a fault with a temperature sensor part through the test, however, the flow meter output has continued to operate enabling the flow rate error to be calculated and compared.

It is clear from Figure 44 and Figure 45 that the change in overall heat metering accuracy is mainly due to the accuracy of the flow rate measurement.

The vortex, rotary and one of the ultrasonic heat meters (B) initially showed a very large energy and flow error which then decreased. This is very likely due to an initial large quantity of circulating dirt and air which then gradually cleared.

The early test result showed a large difference in errors between the two ultrasonic heat meters when subject to high levels of air and dirt. However, once the initial high levels of air and dirt had subsided the error levels of both ultrasonic heat meters stabilised which suggests that they are not affected by lower levels of circulating dirt. Both ultrasonic heat meters (A and B) were installed adjacent to each other and in the same section of horizontal pipe, and strictly in accordance with the manufacturers' instructions which included orientation to minimise susceptibility to entrained dirt (meter B was downstream of A). Therefore the results show that the ultrasonic meters are relatively insensitive to low levels of circulating dirt but that one meter was much more sensitive to the higher levels of air and dirt present at the start of the test.

As the test has progressed the continuous circulating dirt level appears to have caused a gradual and continuous deterioration in the accuracy of the vortex and rotary meter, with the vortex showing an increasingly positive error and the rotary an increasingly negative error in heat energy. However the accuracy of the two ultrasonic heat meters appears to have stabilised.

Since the flow rate error variations also appeared to follow the same trend as the energy errors it can be inferred that the reference electromagnetic flow meter was also largely unaffected by the dirt.

Further research is recommended to investigate the longer term effects of air and especially dirt on under and over reading of heat energy, and also to determine whether there are systematic differences between meter types including between different makes and model of ultrasonic meter.

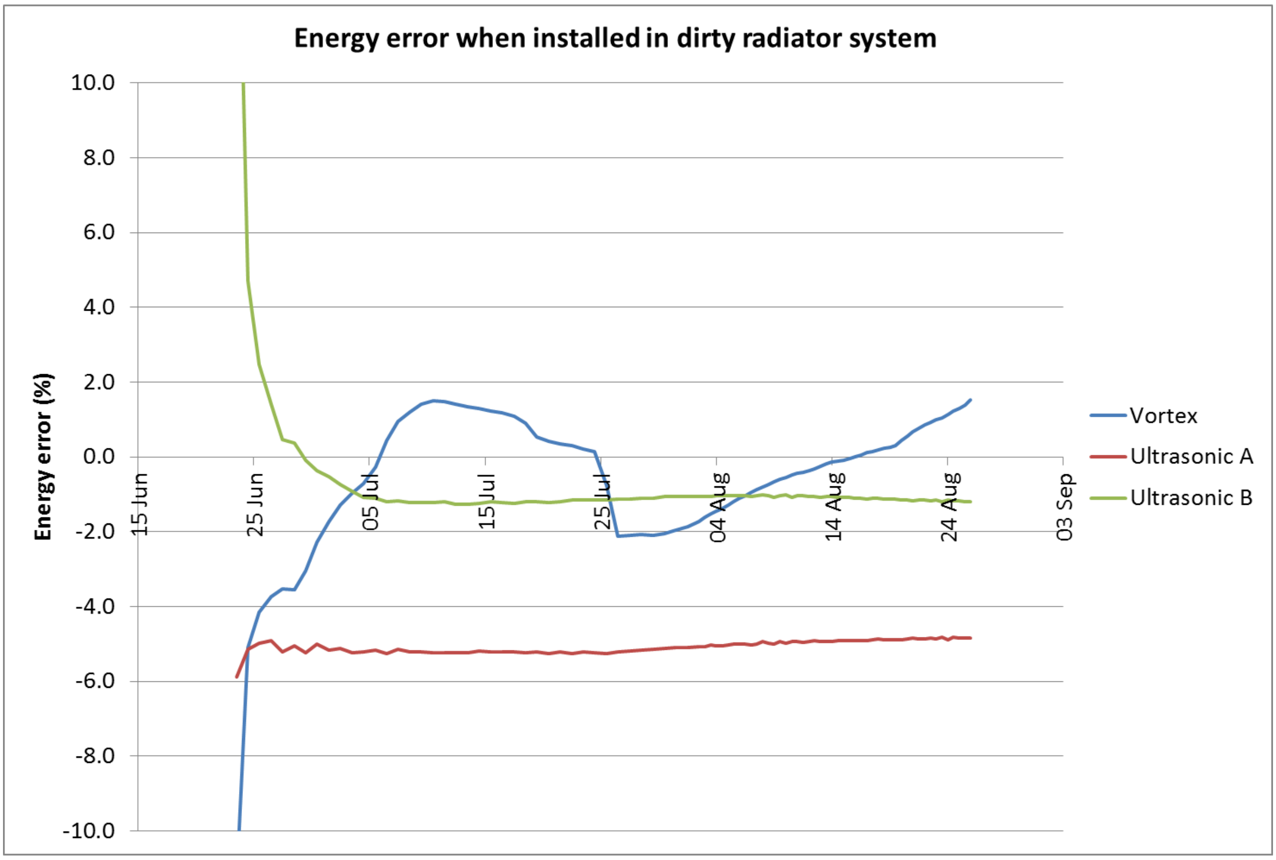


Figure 44: Variation in energy error for heat meters installed in dirty heating system

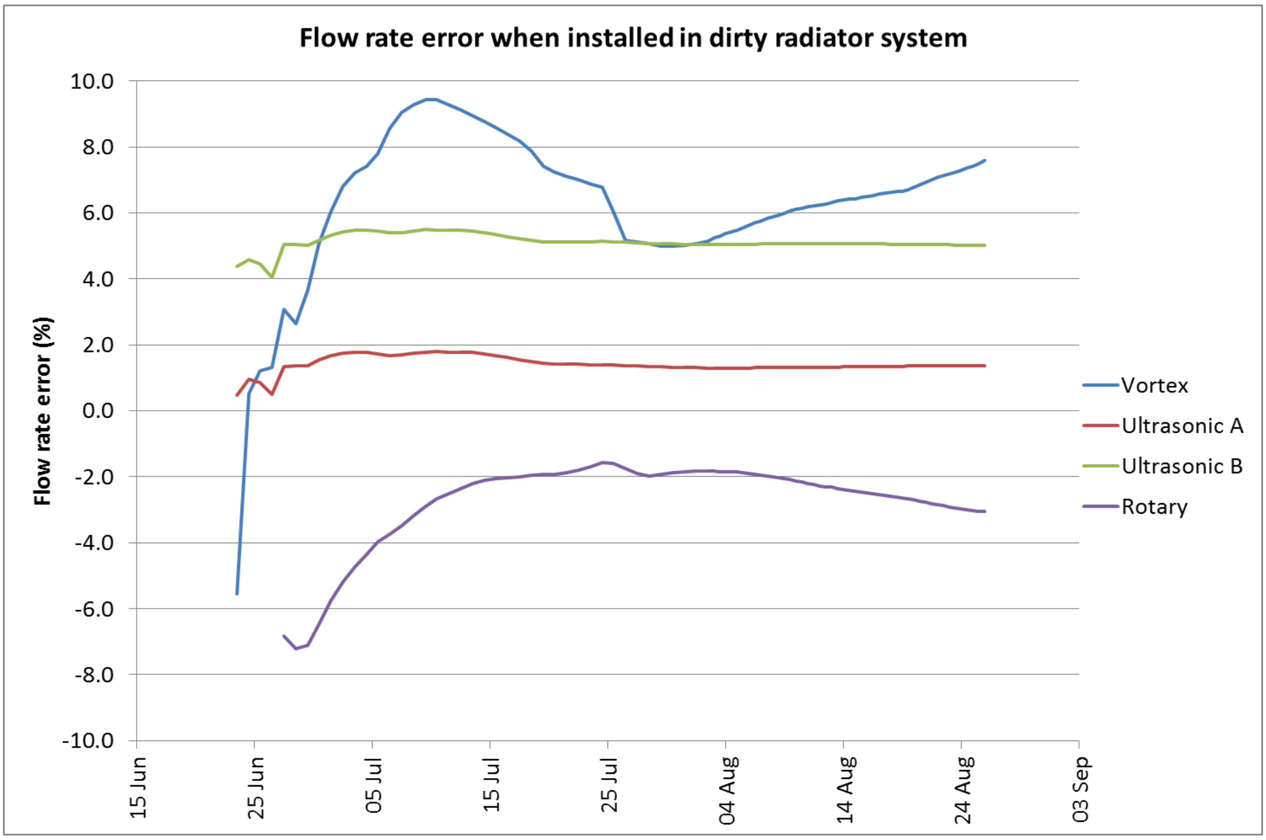


Figure 45: Variation in flow error for heat meters installed in dirty heating system

Used meters

Six used heat meters (DN20 vortex type) were tested over a range of flow rates to assess comparability between individual meters and the MID accuracy classes for flow rate and energy. The heat meters had been in use for over three years in domestic applications and were tested 'as-found' without recalibration. The qp value (the highest value of flow q that is permitted permanently for the heat meter to function correctly) for these heat meters was stated by their manufacturer as 2.5 m3/h. The derivation of the maximum permitted errors for flow rate and energy, taking into account qp, is shown in Appendix E.

Percentage flow rate errors from the tests are shown graphically in Figure 46 and energy errors (for a fixed dT of 5K) are shown in Figure 47.

The findings for the old DN20 meters are similar for the new DN25 and DN40 heat meters in that there is nearly constant over measurement of flow rate but that energy measurements were mostly within the MID Class 2 requirement. However, a peculiarity with the old DN20 meters was that both flow and energy errors decreased at low flow rates which was the opposite of what was expected and different to the new DN25 and DN40 meters. This could be due to the fact that any possible build-up of scale or dirt on the meter would have a more significant effect at lower flow rates.

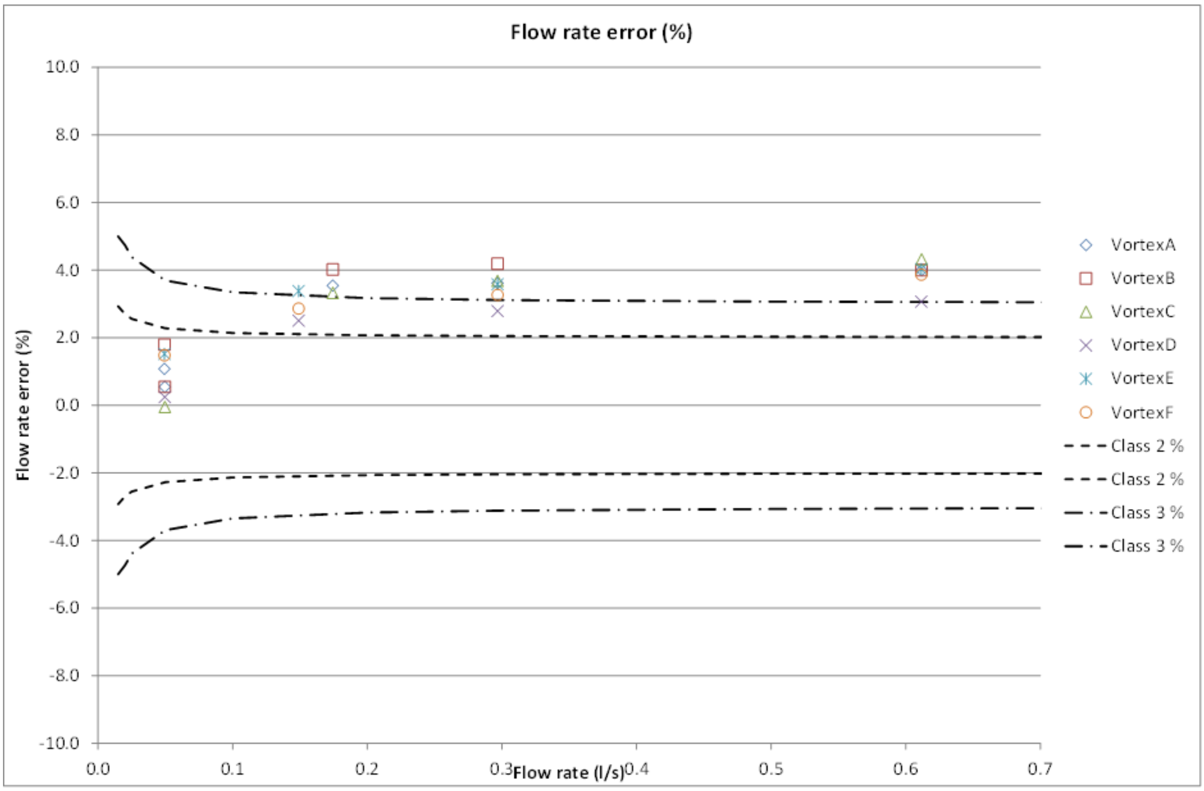


Figure 46: DN20 heat meter flow rate error – old meters

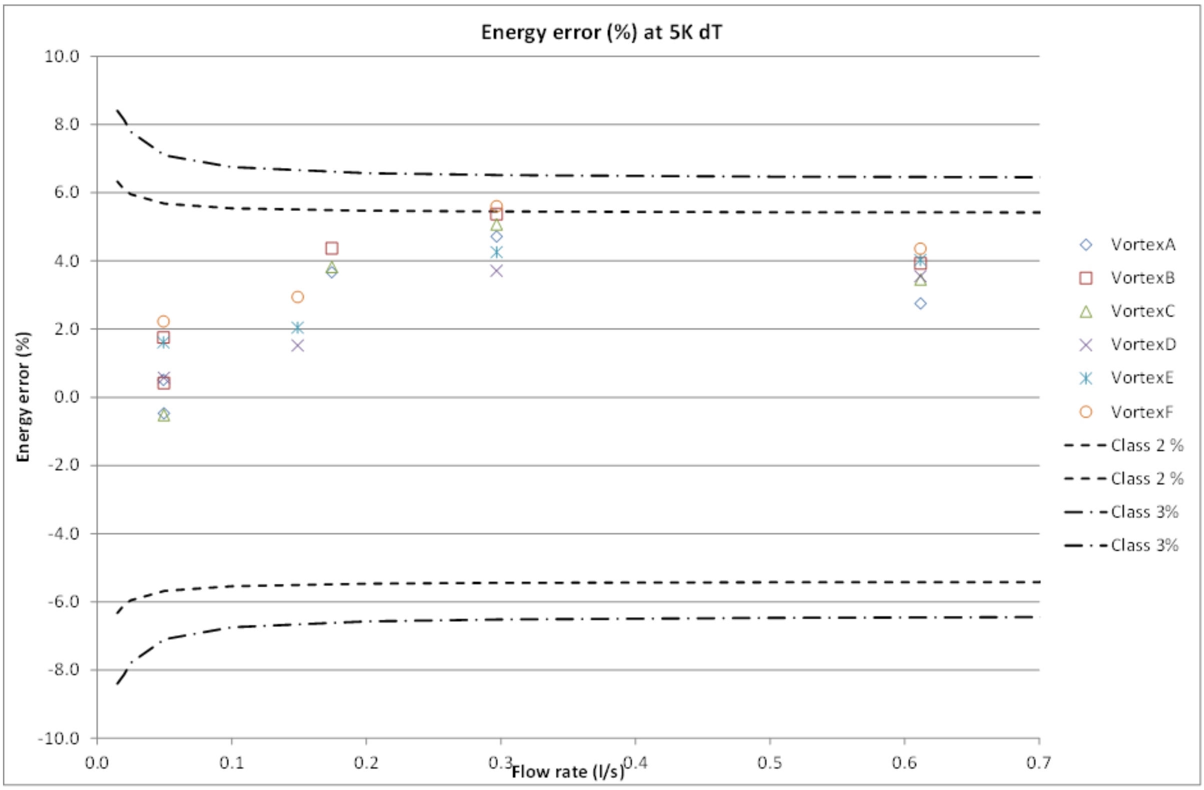


Figure 47: DN20 heat meter energy error (at 5K temperature difference) – old meters

Summary

A brief summary of the above findings is presented hereunder.

- The results of the flow calibration tests indicated that the DN 25 meters were outside the MID class limits for flow measurement but within the MID class limits for energy measurement. The DN 40 meters were within the MID class limits for both flow and energy measurement.
- The tests carried out to measure flow with incorrect orientation of the meters did not produce any significant additional error to the calibration tests, except for an increased error for the vortex type meters at high flow rates.
- The tests carried out to measure flow with air entrainment did not produce any significant additional error to the calibration tests, except for an increased error for the vortex type meters at high flow rates, and a failure of the ultrasonic type meters to take any measurement.
- The combination of air entrainment and incorrect orientation did not result in any change to the flow measurements taken when compared to measurements taken with the individual installation errors.
- The tests carried out to measure flow with the meters installed in close proximity to bends did not produce any significant additional error to the calibration tests, except for an increased error for one of the ultrasonic type meters.
- The tests carried out to measure flow with a combination of air entrainment and installation in close proximity to the pump did not produce any significant error in addition to the calibration tests, except for the combination of air and meter installation just before the pump which had a significant increase in error on the vortex meter. As noted before, the ultrasonic meters ceased to operate with air in the flow.
- The tests carried out to determine the effect of incorrect configuration of the meter for the system glycol concentration confirmed that this error could be corrected by calculation if the correct system glycol concentration is known.
- The results of the temperature sensor calibration tests confirmed that whilst the actual temperature measurements had errors of up to half a degree, the matching of the temperature sensors reduced the temperature difference measurements to the order of one tenth of a degree.
- The tests on different mounting methods for temperature sensors established that temperature sensors should be installed within the fluid flow using pockets or ‘Binder’ (self-sealing test plug) points for the required accuracy. These tests showed that strap-on and surface sensors were considerably less accurate. The highest inaccuracies during this exercise were those caused by installing the two temperatures sensors differently from each other.

- The tests on transient operation in the laboratory test rig showed that variations in flow rate and temperature generated errors which approached the MID class limits for energy measurement for two out of the four meter types tested.
- The tests on transient operation on the heat pump test rig resulted in errors which often exceeded the MID class limits, particularly but not exclusively where strap-on sensors were installed.
- The tests on used meters three years after installation did not demonstrate any significant deterioration in performance.
- The tests on dirt showed the heat meters had a widely different susceptibility to dirt. There was also a marked difference between the two ultrasonic heat meters. One ultrasonic heat meter displayed a large over reading of energy and flow and the vortex showed a large under reading. The other heat meters including the other ultrasonic meter, the rotary meter and the reference electromagnetic flow meter showed much less sensitivity to dirt.

Although the majority of the tests were carried out on the DN25 meters, it should be quite possible to extrapolate these results. The flow calibration tests were actually carried out on both DN25 and DN40 meters and some variance in the results could be noted. However, the main inaccuracies were noticed with the temperature sensor installation tests, and these components are completely unrelated to meter size.

Table 17 and Figure 48 provide a representation of the different flow measurement errors over the test range.

FLOW MEASUREMENT ERROR	Vortex	Ultrasonic	Ultrasonic	Rotary
Flow calibration	3.85%	2.37%	2.92%	3.69%
Incorrect orientation	0.34%	-0.96%	2.87%	2.83%
Air entrainment	5.12%	0%	0%	3.22%
Air + incorrect orient	5.08%	0%	0%	3.27%
Two bends upstream	3.78%	2.79%	1.71%	3.54%
Two bends + incorrect orient	3.92%	4.87%	2.75%	2.81%
Before pump	2.10%	2.15%	1.83%	1.85%
After pump	1.90%	2.15%	0.54%	2.82%
Before pump + air	8.06%	0%	0%	2.98%
After pump + air	1.82%	0%	0%	1.42%
10% Glycol in meter calib for water	3.34%	2.80%	3.70%	3.85%
30% Glycol in meter calib for water	3.10%	3.30%	2.29%	3.14%
Before pump + two bends	2.90%	1.73%	2.63%	1.59%
After pump + two bends	1.95%	-1.10%	2.27%	2.41%

Table 17: Flow measurement errors for different installation effects at qp

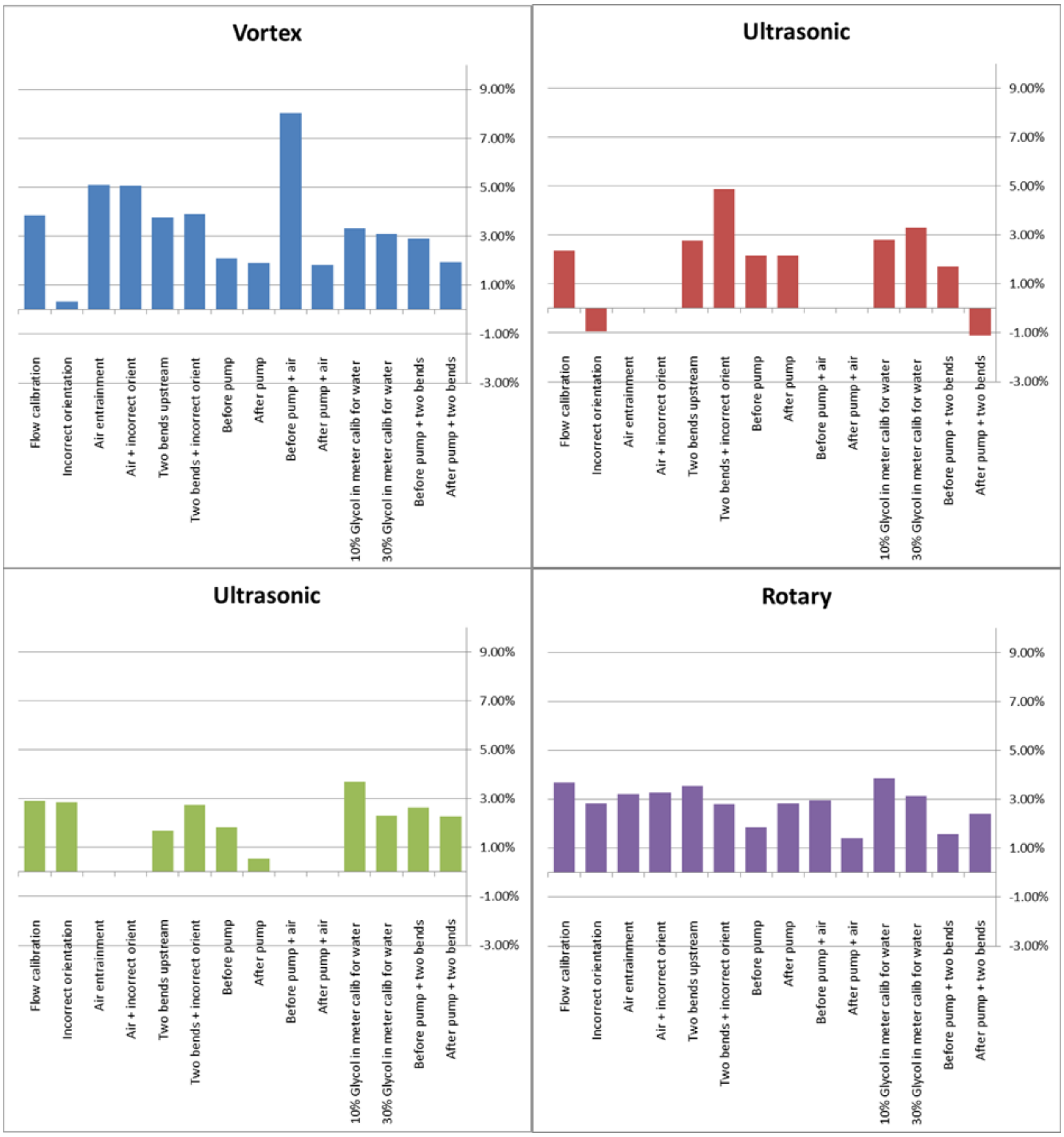


Figure 48: Flow measurement errors for different installation effects at qp

Estimating the impact of errors in the field

In this section the analysis of data from site audit visits is used to identify the proportion of sites with different kinds of heat meter installation errors. This analysis and the results of the laboratory tests presented in *Data from test programme* allow the impact of each of those types of error to be quantified. As well as providing information on which errors it is most important to avoid, this information can be combined to give an overall estimate of the metering errors in the current RHI program.

The work described has measured the inaccuracies due to a wide range of effects which can occur when errors occur in heat meter installation. It is clear that the main value of this work is to identify the areas in which particular care is required, and this will provide guidance both to installers and auditors as to which types of error it is particularly important to avoid.

Armed with all this new information, it is also possible to make an estimate of the combined impact of all the sources of uncertainty across the whole population of heat meters installed in the UK.

Systematic and random errors

In conventional error analysis, for example (Taylor, 1982), a clear distinction is made between systematic and random errors.

Systematic errors in an instrument are those which are essentially constant, and thus appear in every measurement taken. Their effect can be eliminated by the process of calibration: the sensor is compared with a reference sensor, and from that point on all its readings are corrected accordingly. Most instrument users, and indeed manufacturers, will strive to eliminate systematic errors by calibration of their instruments against reliable references.

Random errors are the variations which inevitably occur between measurements. There are distinguished by the fact that, in most circumstances, their impact can be reduced by carrying out additional measurements and combining the results.

Holman (2001) raises two issues with this approach. The first is that all genuinely systematic errors should already have been calibrated out, and the second is that any which cannot be calibrated out are effectively random errors. For example there will be random errors in the original reference measurement, and random errors in the comparison between this and the sensor. His approach is therefore that all errors should be treated as though they are ‘random’.

In the situation considered in this study it is possible that a fault installing a meter will result in a systematic error at a particular site, which cannot be calibrated out. However, the identity of the site is itself likely to be random, and so the Monte Carlo approach to combining errors which is used below is therefore still appropriate.

Previous approaches to combining heat metering errors

In EN1343 the errors due to the different components which make up a heat metering system are combined by adding their maximum possible magnitudes. For example if a heat metering system used a temperature difference measurement system with an uncertainty of ±1% and a flow meter with accuracy ±2%, then the overall accuracy would be estimated to be ±3%. This approach implicitly assumes that the errors are small. In a heat metering application the temperature difference and flow are multiplied together to obtain the result and the calculation below shows how these errors propagate through this process. To simplify the arithmetic both the temperature difference and flow are assumed to have the value one, so the corresponding product is also one. In this case if both sensors read high the actual worst case reading would be given by:

$$(1 + 0.01) * (1 + 0.02) = 1 + 0.01 + 0.02 + 0.01 * 0.02$$

Only if the errors are sufficiently small can the last term be ignored, and the overall error is then 3%, as given by simple addition used in EN1343.

This approach effectively calculates the absolute worst case error. It effectively assumes that all individual sources of error conspire (in this case by being the same sign) to generate maximum error. This is a highly pessimistic approach. In general flow meters will be paired randomly with temperature measurement equipment. In a number of cases the worst scenario will be realised: temperature sensors which over-read by 1% will be paired with a flow meter which over-reads by 2% and the whole system will over-read by 3%. In some other cases however over-reading flow meters will be paired with under-reading temperature sensors and some error cancellation will occur. This could reduce the error to 1%.

It is possible to address this issue only by considering the probability distribution of the errors, rather than the errors themselves. If the sources of error are assumed to be statistically independent (that is the value of one error does not depend on the value of the other) and their magnitudes remain reasonably small then the variance of the total error will be equal to the sum of the variances from each error source.

If the shape of the distribution of each error source is known then the tabulated error values can quickly be turned into standard deviations, and hence into variances. A popular assumption is that the errors are normally distributed, and that they represent 95% confidence intervals. For this particular distribution it is well known that the 95% confidence interval spans a range of ±1.96 standard deviations. So for the example above the standard deviations of the two error sources would be 1/1.96% and 2/1.96% respectively. These are easily converted to variances by squaring them, and adding the results gives the variance of the overall error. The square root of the result gives the standard deviation of the total error.

A further advantage of assuming normal distributions is that the sum of any number of normally distributed errors will itself be normally distributed. The 95% confidence interval of the total error is therefore given by multiplying the calculated standard deviation by 1.96. The whole calculation is therefore:

$$1.96\sqrt{\left(\frac{1}{1.96}\right)^2 + \left(\frac{2}{1.96}\right)^2}$$

The first observation is that the factors of 1.96 cancel out, and the 95% confidence interval of the overall error is simply ±√(12 + 22) = ±2.2%. One consequence of this is that if, for example, the individual errors were assumed to be 99% rather than 95% confidence intervals the factor would change to 2.58, but the resulting 99% confidence interval would still be ±2.2%.

This analysis forms the basis of the ISO method for combining measurement errors (ISO/IEC/2008). It is the analysis approach used in the previous analysis of heat metering errors described by Martin (2014). That study identified that some of the error bands were not symmetrical about zero, and used a centring process to account for this.

There are a number of shortcomings in this calculation method, due to the following assumptions which have been made:

- The errors need to be relatively small here to account for the fact that the relevant quantities are multiplied together. The ISO specification allows for any way of combining readings, but errors are still required to be small for their approach to be accurate;
- The errors have been assumed to be statistically independent. This is not essential, but assuming inter-relations between them greatly increases the complexity of the total variance calculation. Once again, the full ISO method does enable such effects to be incorporated;
- The errors have been assumed to be normally distributed. Again this is not essential, but for any other distribution it is necessary to calculate not only the variance but also the distribution of the overall error, to allow the standard deviation to be translated back to a confidence interval. In a small number of cases this can be easily done: for example if there were two individual errors both uniformly distributed the overall error would have a truncated triangular distribution. For a larger number of sources of error or different distributions however the process becomes much more complicated. In many instances there are strong arguments against the use of normal distribution. These are discussed in more detail in Appendix F to this document.

One way to overcome these issues is by the use of Monte Carlo analysis.

An introduction to Monte Carlo analysis

Monte Carlo analysis is an alternative way of combining the impact of individual sources of error. It works by generating imaginary cases, in which the value of each error has been obtained by taking a random sample from the assumed distribution. The results are then combined, to give the overall error for that particular case. The process is repeated many times, giving a whole set of possible measurement situations. Confidence intervals and, if required, distributions can then be calculated from this population of possible outcomes.

Because the process is numerical, it can dispense with the assumptions required for conventional error analysis. In particular:

- The sampled (erroneous) values for each quantity can be combined in any way required, including multiplication, as required for heat metering. Thus the assumption of small errors is no longer required;
- the error values can be sampled from distributions which are not statistically independent if this is believed better to represent reality;
- The error values can be sampled from any distribution required, removing the need to assume normally distributed errors throughout.

The use of the Monte Carlo technique is widely documented, for example by Martinez and Martinez (2008). BIPM (2008) also gives a very through introduction to the technique. A paper from the UK National Physical Laboratory (Cox & Harris,2003) gives an example of its use in a non-linear situation where the conventional analysis described above fails.

To demonstrate the process, we can analyse the case considered above, in which temperature difference and flow errors were normally distributed with 95% confidence intervals of ±1% and ±2% respectively. As before, both temperature drop and flow are assumed to have the value one. The analysis begins by generating a large number of values (in this case one million) of pairs of temperature difference and flow measurements which might be seen under these circumstances. The pairs of values are then multiplied together, to generate the heat readings which would be seen. The histogram below (Figure 49) shows the distribution of the result.

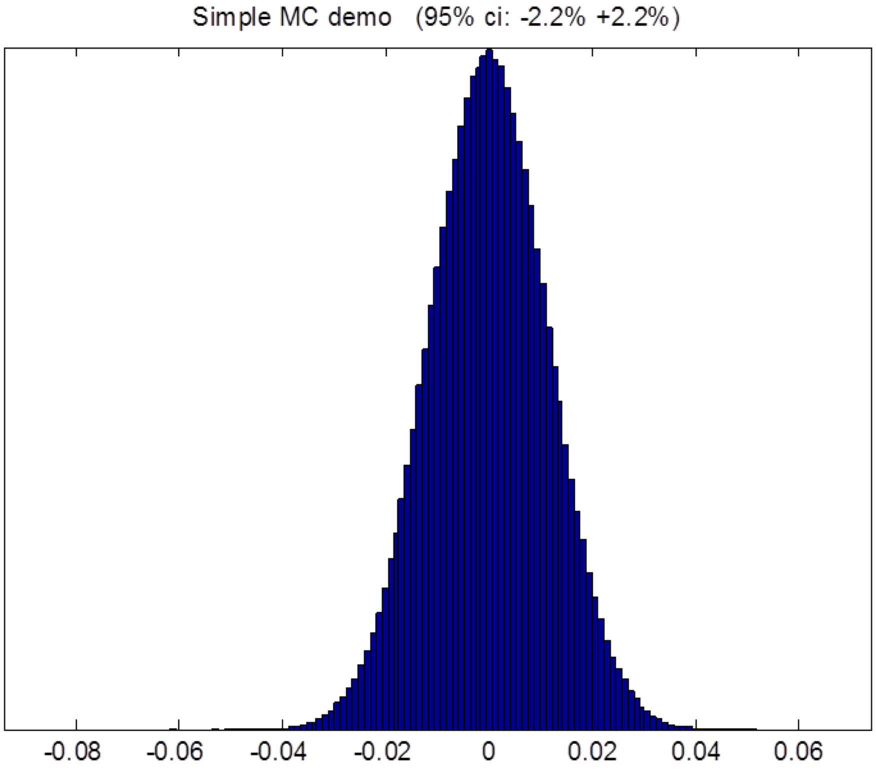


Figure 49: Example distribution

The 95% confidence interval of this distribution can be easily calculated. It is ±2.2% as expected from the discussion above. Also as expected the distribution appears to be approximately normal.

This very simple demonstration has been primarily to demonstrate how the Monte Carlo process works in practice. However it has also shown that, for a case simple enough also to be treated analytically, it delivers results which are compatible with that approach.

Monte Carlo approach to heat meter data

The required analysis falls into two sections:

- identifying the required data, in terms of the relevant sources of error, their impact and the probability of their occurrence, and
- implementing the necessary calculations.

Data requirements

The causes of error present in a heat metering application have been identified and discussed in *Analysis of information on heat meter accuracy*. They are summarised in Table 18 below. The table also indicates the source of estimates of the level of error which might be expected from each cause.

Source of error	Source of estimated impact
Basic instrument accuracy	Manufacturer's EN1343 class
Flow measurement errors	
Incorrect flow meter orientation	BRE tests (Air and orientation)
Upstream flow perturbation	BRE tests (Bends)
Gas entrainment	BRE tests (Air and orientation)
Dirt in system fluid	BRE tests (not yet completed)
Proximity to pumps	BRE tests (Before & after pump)
Mounting in flow rather than return	Calculated values
Impact on flow being measured	Calculated values
Temperature measurement errors	
Mounting sensors by strapping to the outside of the pipe	BRE tests (T sensor mounting)
Proximity of other heat sources to sensors	Calculated values
Heat calculation errors	
Use of system working fluids other than water (heat calculation)	Physical fluid properties
Use of system working fluids other than water (flow calibration)	BRE tests (Glycol)
Excessive sampling intervals	Calculated and reported values

Table 18: Sources of Error

The key elements required for a Monte Carlo analysis are the probability that each type of error might actually occur on a given site, and the distribution that error might assume.

Where possible, the probability of an error occurring is based on the results of the audits of RHI and RHPP installations. These included a total of 410 RHI sites and 276 RHPP sites. Two values have been derived:

- Since the two samples are separate (a given site cannot feature in both types of audit) the first value is calculated using a simple weighted average combining results from the two programmes. This has the advantage that it uses all of the information available, and gives an estimate of metering errors across all meters installed. It does not take account of the fact that all the RHPP sites used a particular model of heat meter, but this would only produce a bias if that particular equipment was known to be prone to certain installation errors.
- The second value is calculated using RHI audit information only. This is to allow the impact of errors on the RHI programme to be assessed.

Table 19 gives the frequency of occurrence of each source of uncertainty using the two calculation methods.

The two values given for the impact of strapped on sensors and missing insulation represent the BRE results for continuous and cycling operation. It is assumed that each system spends equal amounts of time in each operating mode.

Source of error	Probability of occurrence (all audit data)	Probability of occurrence (RHI audits only)
Basic instrument accuracy		
Class 2 flowmeter accuracy	100%	100%
Temperature difference accuracy	100%	100%
Calculator accuracy	100%	100%
Flow measurement errors		
Incorrect flowmeter orientation	9.5%	13.2%
Upstream flow perturbation	3.3%	2.1%
Gas entrainment	5.0% (Estimated)	5.0% (Estimated)
Dirt in system fluid	To be estimated when data is available	
Proximity to pumps	0.2%	0.2%
Mounting in flow rather than return	4.0%	4.0%
Temperature measurement errors		
Mounting sensors by strapping to the outside of the pipe	2.8%	2.0%
Missing insulation	1.6%	0.7%
Proximity of other heat sources to sensors	100%	100%
Heat calculation errors		
Use of system working fluids other than calibrated value (heat calculation)	25% (Estimated)	25% (Estimated)
Use of system working fluids other than calibrated value (flow calibration)	25% (Estimated)	25% (Estimated)

Table 19: Frequency of occurrence

Table 20 uses the data sources described to determine the impact of this case for one of the ultrasonic meters tested. Similar tables have been prepared for the remaining three meters, and these are reproduced in Appendix H.

In the case of gas entrainment this particular heat meter stops working altogether and displays an error message. It is assumed that in this case the fault would be rectified in practice.

Note for the discrete distributions assume that equal probability is assigned to each point so, for example in the case of mounting sensors by strapping it is assumed that at 50% of the affected sites this results in a 2.4% error, and at 50% in an error of 4.2%. These two values correspond to the errors when the system is running continuously and when it is short cycling, so in this particular case this represents an assumption that the system spends equal amounts of time in each operating mode. This is not a restriction of the analysis software, which allows any probability to be assigned to each point, but simply a reflection of the fact that no more detailed information is currently available.

Source of error	**Probability of occurrence**	**Error distribution**
Basic instrument accuracy		
Class 2 flowmeter accuracy	100%	Truncated normal ±2.0%
Temperature difference accuracy	100%	Truncated normal ±1.4%
Calculator accuracy	100%	Truncated normal ±0.8%
Flow measurement errors		
Incorrect flowmeter orientation	9.5%	Discrete 5.0%
Upstream flow perturbation	3.1%	Discrete -0.8%
Gas entrainment	5.0% (Est)	n/a
Dirt in system fluid	To be added when data is available	
Proximity to pumps	0.2%	Discrete 0.4%, 1
Mounting in flow rather than return	4.0%	Uniform 0.3%, 2.0%
Temperature measurement errors		
Mounting sensors by strapping to the outside of the pipe	2.8%	Discrete 2.4%, 4.2%
Missing insulation	1.6%	Discrete 5%, -2.5%
Proximity of other heat sources to sensors	100%	Uniform -0.9%, 0
Heat calculation errors		
Use of system working fluids other than calibrated value (heat calculation)	25%	Normal ±1.5%
Use of system working fluids other than calibrated value (flow calibration)	25%	Normal -0.8%, -0.6%

Table 20: Typical analysis for one ultrasonic meter type

Implementation

The required calculation has been implemented in MATLAB. This approach means that the calculation process is fully automated, and also that it can be readily reviewed by others.

The program uses a table to establish the error sources for consideration, and their probabilities of occurrence, using the information determined from the analysis of RHI and RHPP heat meter installation audits. The format of each entry in that table is given in Table 21.

Name of error source	
Probability of this error occurring on a given site	
Distribution type	**Parameters**
Normal	Start of 95% confidence interval
	End of 95% confidence interval
Truncated normal	Start error interval
	End of error interval
Uniform	Start of error interval
	End of error interval
Discrete	Value i (as many as required)
	Probability of value i occurring (same number as values)

Table 21: Error sources and probability of occurrence

The format also allows for a header line, which uses a fictitious distribution called Name to allocate a name to the whole run.

All of the distribution types implemented can be made non-symmetrical by the choice of suitable parameters, allowing the system to analyse non-centred errors with ease.

The program then generates one million sample cases. BPIM (2008) gives a simple formula for the number of cases likely to be required, and concludes that, in general, one million cases will be adequate. (The distribution of each error component is plotted, and its 95% confidence interval calculated as a check. The errors from all sources are combined, and an estimate of the total error tabulated for each case. From these results the overall 95% confidence interval is generated, and the distribution of errors is plotted.

The random errors generated for each individual case are also tabulated. This facility was initially included as a software testing tool for use during the program development, but it does mean that further analysis can be carried out directly, without the need to repeat the whole Monte Carlo calculation.

Results

Figure 50 below shows the result of combining all of the errors listed in Table 18, to determine the overall error associated with the use of heat meter Ultrasonic B in the field. As might be expected from such a diverse range of uncertainties and distributions the result is significantly non-normal in shape.

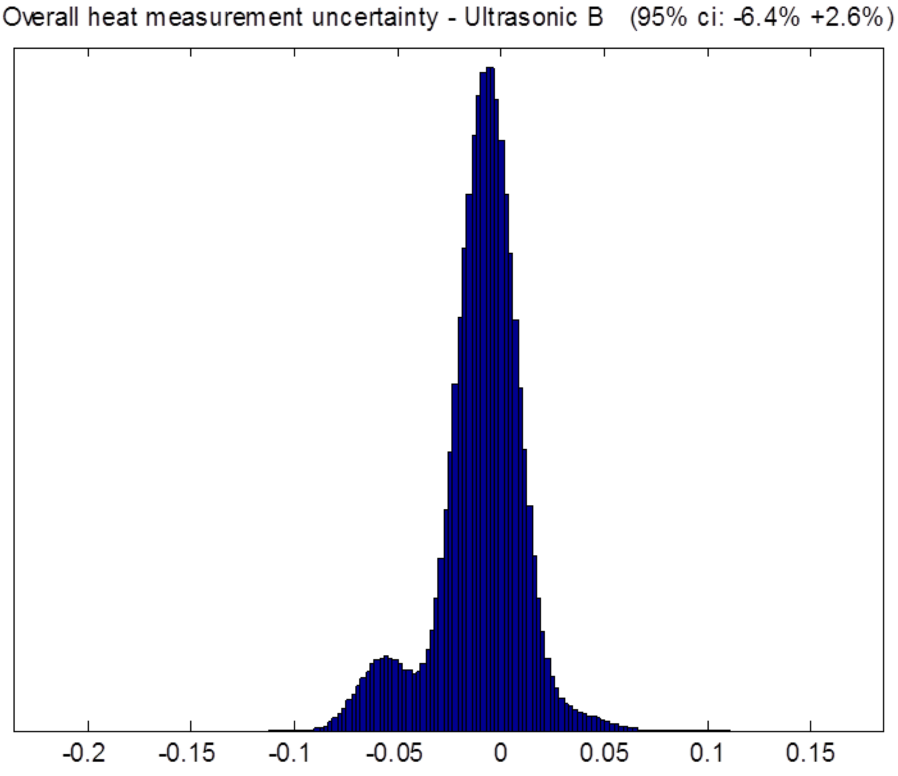


Figure 50: Distribution resulting from combination of errors

In fact, the result is dominated by the main meter uncertainties, which yield the main peak. The behaviour of both ultrasonic meters and the vortex meter follows this pattern. The rotary meter departs slightly from this behaviour because it has a large uncertainty when the sensors are strapped to the pipework of a system which cycles. Table 22 below summarises the results obtained, in terms of 95% confidence intervals, for each of the meters tested.

Meter	Probabilities calculated across whole population	Probabilities from RHI only
Ultrasonic A	-5.3 + 3.1%	-5.6 + 2.7%
Ultrasonic B	-6.4 + 2.6%	-6.6 + 2.2%
Vortex	-4.9 + 3.6%	-5.2 + 3.4%
Rotary	-2.8 + 7.4%	-2.8 + 2.9%

Table 22: Results for 95% confidence intervals

The results in Table 22 indicate that the analysis is, in most cases, relatively insensitive to the choice of sample used to determine the probabilities of error.

These results from the four meters could be combined in any way required. It is particularly useful to combine them with weightings which correspond to the relative numbers of each meter in the RHI. The result is shown below in Figure 51, and has a 95% confidence interval of -5.9 to +2.8%.

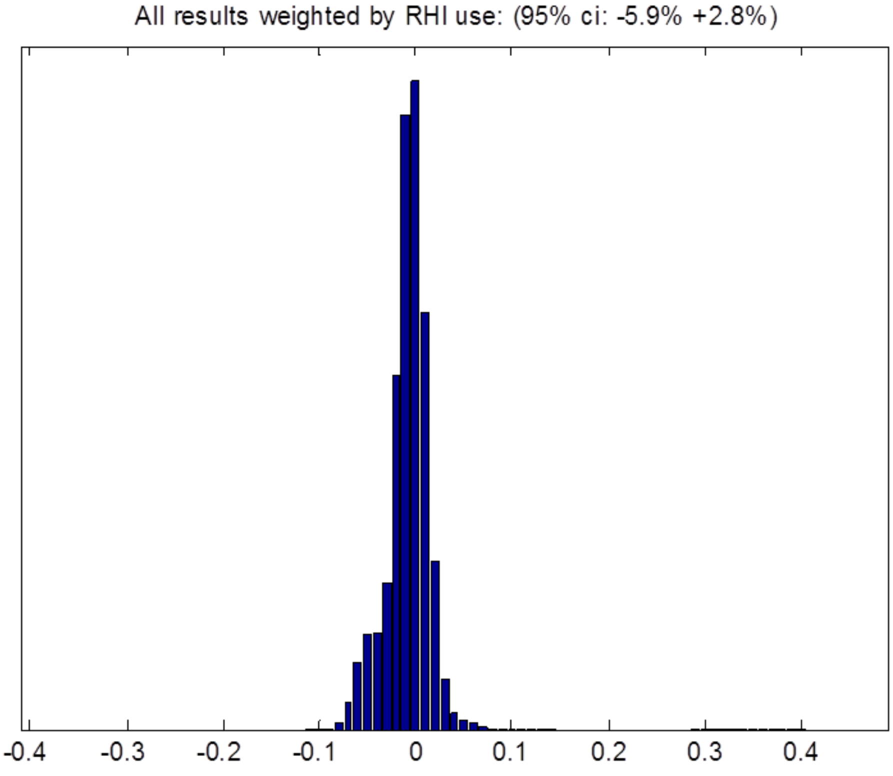


Figure 51: Distribution weighted according to the relative numbers of each meter in the RHI

Summary

The data available from site audits is combined with the statistics for the installed meter types and the laboratory test results for an overall estimate of metering errors.

The Monte Carlo technique is used to combine these two sources of information. To do this some very major assumptions have to be made, and it is stressed that the results represent a ‘best estimate’ of the current combined effect of the different installation problems. These reveal the overall error across each of the four meter types tested. It is known that the types of meter in the field are heavily weighted towards one of the ultrasonic types and the vortex meter. Combining the errors to take account of this weighting indicates that across the whole sample the metering uncertainty has a 95% Confidence Interval of -5.9 to +2.8%.

Heat meter accuracy and recalibration

The purpose of the requirement for a metering specification is twofold, namely to provide a basis for the specification of heat meters that are suitable for the continued implementation of the RHI and to determine a potentially higher level requirement for heat meters to be used for research contracts.

The data collected in *Data from test programme* and the analysis in *Estimating the impact of errors in the field* demonstrate that commercially available meters can produce consistent results with a high level of reliability when installed in accordance with the manufacturers' instructions. Figure 15 to Figure 20 show that the levels of error are generally consistent, within the limits defined by MID Class 2, and follow specific trends. This form of error is relatively simple to correct through appropriate and regular calibration of the meters. As could be expected, the representative sample of new meters on the market provides accurate flow and temperature measurement within the defined error bands.

Further questions that arose through the development of this research and the related test program were

- How is meter accuracy affected by installation effects?
- How is meter accuracy affected by time?
- What could be the financial implications of meter inaccuracy in relation to the RHI?
- Can installation effects facilitate or provide an indirect route to tampering and fraud?
- How can higher accuracy be achieved for research projects?

Underlying these questions is the necessity to establish an appropriate period for the recalibration of meters once they have been installed in the field. The definition of an arbitrarily short recalibration period would involve unnecessary expense in the recalibration of meters that are still providing accurate energy measurements, whilst an unduly long recalibration period increases the risk of meters which are no longer accurate providing incorrect energy measurements, with related financial implications.

This section applies the outcome of the laboratory testing and additional research work to identify possible answers to the above.

Heat meter accuracy

Installation effects

In general terms the test program has demonstrated that the flow meter component of new heat meters is robust and capable of accurate flow measurement even when the manufacturers' recommended installation procedure is compromised by site conditions. On the other hand the test program has also highlighted the fact that the energy measurement of heat meters, which is made up of both flow and temperature measurement, is highly dependent on the appropriate installation of the temperature sensors. It should be noted that the errors associated with heat meter temperature measurement for correctly installed sensors is very low. This appears to be due to the supply of matched pair sensors by the manufacturers. However, errors in the temperature sensor installation can result in substantial inaccuracies in the energy measurement. However whilst new heat meters are sold and installed on the basis of a level of accuracy defined by the relevant MID Class, legislators and suppliers are obliged to define the timeframe for which the installed heat meter can be expected to maintain a defined level of accuracy, before requiring replacement or recalibration.

Long term accuracy

In an attempt to assess the performance of heat meters over time, EN 1434-4(2007) specifies a durability test for flow sensors for heat meters with a basic wear test cycle of one hundred days. Dr Jürgen Rose of the PTB (The National Metrology Institute of Germany) expressed the opinion that the measurement time for this test is too long and too expensive. The MID Annex 1 Clause 5 allows the declaration of durability to be defined over a period of time estimated by the manufacturer. Testing carried out by the PTB found that the durability error increased from 0.2-0.3% for flow rates between 1500 and 3000 l/h to 1-1.5% for flow rates between 15 and 30 l/h. The durability test stress cycles are actually harder than the transient cycles experienced in normal operation. However the durability test does not take into account installation effects such as dirty water and scale build-up.

In high-cycle fatigue situations, materials performance is commonly characterized by an S-N curve, also known as a Wöhler curve. This is a graph of the magnitude of a cyclic stress (S) against the logarithmic scale of cycles to failure (N). S-N curves are derived from tests on samples of the material to be characterized where a regular sinusoidal stress is applied by a testing machine which also counts the number of cycles to failure. Analysis of fatigue data requires techniques from statistics, especially survival analysis and linear regression.

Analysis of differences between steady state and transient heating energy for different meter types and different temperature sensor installations is one of the characteristics by which laboratory tests differ from the field application of heat meters. Figure 52 shows a typical operating cycle for space heating and hot water production in a residential application.

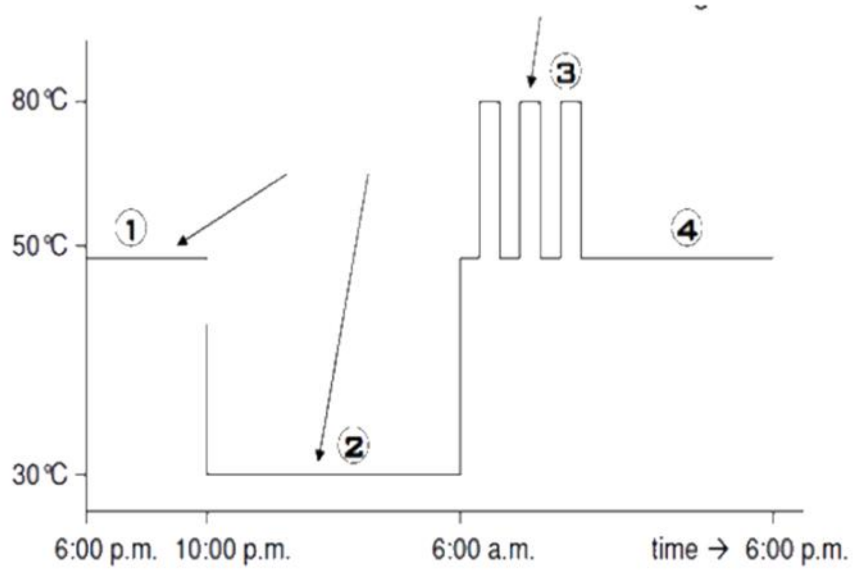


Figure 52: Typical domestic space heating and hot water operating cycle

1=space heating on, 2=space heating and hot water off, 3=hot water heating on, 4=space heating on

On this basis, the German association for District Heating, Cooling, and CHP (AGFW) has developed a higher standard for durability of flow meters than EN 1434-4 and manufacturers may voluntarily submit their meters to AGFW for durability testing. The AGFW test program includes six phases totalling 4800 hours at various temperatures and flow rates. AGRW maintains that its own testing program is more suited to ensure flow meter durability. Whilst in terms of operating hours the AGRW test is significantly less than the five years permitted between calibration in Germany (43,800 hours), the test is designed for greater temperature and flow changes then would be expected in normal operation, in order to increase possible stresses and wear and tear on the meter. Over the test the meter undergoes approximately 1200 load changes in comparison to an estimated 4000 load changes in 5 years of operation.

The accredited Kamstrup laboratory in Denmark tests ultrasonic meters installed in the district heating system on an annual basis. There is a legal requirement for verification or replacement of water meters in Denmark every six years (Danish Safety Technology Authority, 2006). These tests have been carried out since 1997. The 2013 report represents results based on samples of 183 lots of ultrasonic meters, representing a total of 3755 meters. These meters are of size 1.5m3/h. 96.2% of meters fell within the verification limits (equivalent to the MID) and only five batches among the oldest failed, despite the fact that several of the meters were between 12 and 23 years old (Kamstrup, 2013). The 2012 report represents results based on samples of 173 lots of ultrasonic meters, representing a total of 3290 meters. These meters are of size 1.55m3/h. 95.3% of meters fell within the verification limits and only six batches among the oldest failed, despite the fact that several of the meters were between 12 and 22 years old. The same tests are carried out on a smaller sample size of mechanical meters, but none of these meters attain the same level (Kamstrup, 2012).

The Kamstrup information suggests that the lifetime of ultrasonic heat meters is potentially in excess of 20 years and that the majority of heat meters between 12 and 22 years old still met the MID accuracy requirements. No errors or breakdown of the Pt temperature sensors was mentioned since the sample testing is only carried out on the flow component of the heat meter. BRE experience of using PT100 sensors over long periods of time (in excess of 15 years) shows under normal conditions there is no deterioration in accuracy or failure except under conditions of very high humidity and condensation, usually when measuring chilled water temperature. It is thought that under these conditions moisture can sometimes enter the PT100 metal sheaf and cause loss of accuracy and failure, possibly through corrosion of the wire connections. EN 1434-4 specifies three 24 hour damp heat tests under condensing conditions but clearly cannot reproduce exposure to long term damp / condensation conditions.

The system for subsequent verification of heat meters has been in place since the 1980s in Sweden. Whilst this should have generated a substantial historical data file, the data is kept by the accredited inspection bodies and their customers (the heat energy suppliers) and is not in the public domain. The Swedish District Heating Association has plans for publishing a web site for all their members (> 90% of the district heating companies in Sweden) where they can report the results from verification of their heat meters. However this is not yet available (Franzen, 2015).

The limited data available from the German PTB and the tests carried out by Kamstrup indicate that the majority of meters remain within the specified measurement parameters well in excess of the recalibration period, and the recalibration exercise is mainly focused on confirming this. This is within the context of the fact that the historical data from Kastrup is limited to a single meter type, and also that the test requirements for measurement stability over time from PTB allow double the maximum permissible error (MPE) when undergoing recalibration testing.

Heat meter calibration and maintenance over working life

The primary aim of this section is to determine the correct time to calibrate a heat meter, given that these meters are calibrated initially when they leave the factory. The flow measurement component of heat meters may be based on a number of different technologies, some of which have no moving mechanical parts (e.g. ultrasonic), and it is not straightforward to determine the appropriate intervals between calibration. In the field of legal metrology, i.e. anywhere goods must be billed; the measuring device must measure within the maximum permissible errors and be regularly recalibrated, which is sometimes referred to as verification.

Definition of a calibration interval is a form of risk management. The more important the measurement is, the shorter the recalibration period should be. Recalibration is necessary since meters can drift from their factory calibration due to a number of causes, such as dirt, aging of the electronics, physical changes in the measurement sensors, mechanical wear and tear, and other factors. Calibration intervals can be defined by regulation or determined by a historical record and condition analysis.

Factors that affect calibration intervals are the severity of the service, which includes dirty processes or fluids, two-phase flow, surging applications, high and low temperatures, and the level of fiscal and Health and Safety risk attributable to measurement. Excessive suspended solids, entrained air and gas can impact flow measurement.

Different flow meters require different maintenance schedules, and dirty or extreme environments can exacerbate the drift process. Installation is one of the largest sources of uncertainty when transferring calibrations from the laboratory to the field. The development of advanced diagnostics and compensation algorithms is intended to reduce the need and frequency of recalibration (Ballard et al, 2014). Whilst operators and end-users have a strong preference for in-situ calibration, it is common practice to send meters back to a laboratory or a factory for recalibration, with the inherent costs of down-time, replacement, etc. It is simpler, easier, cheaper, and more reliable to recalibrate a meter on a purpose built test rig than to set up a calibration rig on site. Most site calibrations are limited to very large meters which present specific challenges making them difficult to remove for off-site calibration.

Table 24 presents the different calibration intervals for water meters and heat meters where identifiable throughout the EU. This data was not available for all EU states and this could be attributed to the fact that not all EU states have heat metering applications, for climatic or other considerations. A second reason could be related to the state of implementation of the MID in different states. Two different sources of data were used to produce this table, and the values for heat meters do not always agree between these sources. The calibration interval for heat meters varies between two and ten years, with the majority of countries stipulating an interval of four to five years. The interval between calibration for water flow meters varies between two and sixteen years, with the majority of countries stipulating an interval of five to six years. The water meter data is being presented for comparative purposes, since the flow measurement component of a heat meter is basically a water meter. It is noticeable that the interval between calibration for heat meters is generally shorter than that for water meters. This could possibly be related to the cost of provision of heat in comparison to water, as well as the added complexity that a heat meter represents when compared to a water meter.

Whereas no specific justification could be identified to establish the choice of recalibration intervals by the various states shown in Table 23, it is of interest to understand the sampling procedure which is generally the choice of states which have an established heat metering industry. The following sections examine the systems in place in Denmark and in Sweden which have an established heat metering industry and for which information was available.

REVERIFICATION INTERVALS IN YEARS	WATER METERS[1]	HEAT METERS[1]	DISTRICT HEAT METERS[2]	*Notes*
AUSTRIA	5	-	5	
BELGIUM	16*	8	-	* Water meters 8 years if >10m^3/h
BOSNIA HERZEGOVINA	5	-	-	
BULGARIA*	2 or 5	2 or 5	2	* Water meters depends on installation location - heat meters depends on size
CROATIA	5	-	3*	* 5 for ultrasonic meters
CYPRUS	-	-	-	
CZECH REPUBLIC	6	-	4	
DENMARK	Statistical control system		6	
ESTONIA	-	-	2	
FINLAND	3	-	-	
FRANCE	-	-	-	
FYROM	5	-	-	
GERMANY	6	8	5	
GREECE	-	-	-	
HUNGARY	4	-	6	
ICELAND	Statistical control system		-	
IRELAND	-	-	-	
ITALY	-	-	-	
LATVIA	4	2	-	
LITHUANIA	6	4	2*	* 4 for domestic meters < 1.5m^3/h

LUXEMBOURG	10	-	-	
MALTA	-	-	-	
MONTENEGRO	5	-	-	
NORWAY	-	-	5*	* for flowmeter only - 10 for temperature and calculator
POLAND		5/10	4	
PORTUGAL	15	-	-	
ROMANIA	5	4	4	
SERBIA	5	-	-	
SLOVAKIA	6	4	-	
SLOVENIA	5	-	5	
SPAIN	-	-	-	
SWEDEN	-	-	5*	* for flow >1.5m^3/h - 10 for flow > 1.5m^3/h - 10 for temperature meter
SWITZERLAND		5	-	
THE NETHERLANDS	Statistical control system		-	
TURKEY	10	-	-	
UK	-	-	-	

1. From www.welmec.org Country Info accessed 26 May 2015

2. From www.euroheat.org/Files/Filer/.../Publications/billing_meteri… · XLS file · Web view accessed 11 June 2015

Table 23: Verification intervals for water and heat meters in EU states

Danish Sampling Procedure

The third edition of MDIR 07.01-01, the Measuring Technical Directive for district heating (energy) meters defines the control system for heat meters in operation. The directive places the obligation on the district heating supplier to establish a structured control system to provide sufficient assurance that heat meters in operation do not exceed twice the maximum error permissible at the time of initial calibration. The control system should cover all components of a heat meter. It is suggested that the minimum requirement for sufficient assurances could be an acceptable quality level (AQL) of 4%. The AQL is the worst tolerable process average (mean) in percentage or ratio that is still considered acceptable.

Sampling based quality control systems could be based on either DS/ISO 2859 Sampling procedures for inspection by attributes or ISO 3951 Sampling procedures for inspection by variables. MDIR 07.01-01 is based on DS/ISO 2859.

The selection of samples must be such that the sample results may be considered representative of the meter lot, for example, the meters should have the same measuring principle, should be of the same size, and should have been installed for the approximately the same amount of time. The sample number is dependent on the batch size and for single sampling this varies from all meters for a batch size of five to 125 meters from a batch of 3200.

The sampling procedure outlines the following steps:

- The meters in the sample must be taken at random from the batch
- Meters must be dismantled and returned to the laboratory in a safe manner. This includes stopping the ends to prevent drying out.
- Details of the installation, including the condition of any strainers, and the dismantling procedure should be recorded and included in the subsequent analysis of the results.
- Any meters showing signs of damage incurred during transport should be excluded from the sample. It is suggested to dismantle two meters more than indicated by the sampling plan to allow for this contingency.

The district heating supplier is obliged to either replace or sample the meters every six years. The verification of the meters must be performed by an accredited laboratory.

Should there be any indication that certain meters exceed the allowable limits of measurement, the supplier must immediately investigate these meters, irrespective of the normal quality control sampling system. This indication could consist of justifiable complaints, reports from third parties using similar meters, etc.

The recalibration procedure is to be carried out at three different flow rates with three associated temperature differences.

On the basis of the outcome of the tests, the test laboratory must notify the district heating supplier whether the batch may continue to remain in use for another three or six years, or whether the batch should be replaced within one year.

Swedish regulations and guidelines for the periodic inspection of heat and water meters

STAFS 2007:2 stipulate the provisions for periodic inspection of household heat and water meters. They are complementary to STAFS 2006:5 regulations and general guidelines for water meters and STAFS 2006:8 regulations and general guidelines on heat meters.

These provisions define the time interval for periodic inspection of the meters. The periodic inspection can include calibration, examination, and permissible service or repairs such as cleaning, replacement of batteries, and replacement of worn or faulty parts. After the stipulated time interval the meter should be dismantled for inspection. It is recommended that the ends of the meter be plugged to ensure that the meter does not dry out and that the inspection checks be carried out as soon after dismantling as possible.

In the regulation STAFS 2007:2 there are two options for subsequent verification, sampling or testing of all meters. Sampling is mostly used for smaller heat meters. In a batch larger than 50 meters one can pick 20 % of the flow sensors and 10 % of the calculators and temperature sensors for subsequent verification. If the meters are going to be used again for a new five or ten year period, they have to undergo maintenance and repair where the meters are cleaned and worn parts replaced. All meters must undergo an approved calibration verification after maintenance and repair before being put into use for a new period.

The time interval between periodic inspections can be either five or ten years, depending on the size of the meters.

The regulation permits the Swedish authority SWEDAC to authorise longer time intervals between inspections should a meter distributor demonstrate that the technical performance of the meters justifies this.

Summary of findings

Limited data is available on the performance of heat meters over time, although northern European countries have mature systems in place for the periodic inspection of sample meters representative of the installed batch. This in itself implies that the accuracy of heat meters with time is not expected to deteriorate significantly. On the basis of the two systems examined, it is suggested that sampling should be carried out every five to six years, although in specific circumstances this could be extended to up to ten years. The main difference between these systems and the context of this research is the fact that most systems are designed for the end users of district heating systems, whereas this work is weighted towards the recipients of RHI payments or grants.

Heat meter installation arrangement, tampering and fraud

The error analysis from the test program highlighted the fact that the majority of installation errors had a minimal effect on the flow (and subsequently the energy) metering. Whilst the data indicates that the majority of flow readings taken during the calibration tests tend to overestimate the actual flow, this is a constant variance and can be taken into account when establishing the financial relationship to metered heat. Furthermore the corresponding energy readings fall within the MID Class parameters and therefore the meters comply to the accuracy of measurement required for energy, which is the metric on which payments are based. In addition, it is interesting to note that although the number of used meters tested was limited, these meters showed a tendency to under-read slightly, unlike new meters of the same type which seemed to over-read slightly.

Before presenting any conclusions in relation to the possibilities of tampering and fraud, it is essential to consider the context within which this might be expected to take place. Published literature on the accuracy, reliability, calibration, etc. of heat meters is completely focussed on their application in district heating schemes, and indeed one of the primary goals to be met by implementation of the MID is to ensure that the consumer (in this case of district heating) is not overcharged for the service received. In such a context the main motivation for fraud would be to attempt to cause the meter to under-read, as is the case with domestic electricity and gas meters. However, within the framework of the RHI, the consumer is actually reimbursed for the generation of renewable heat, so the motivation for fraud would be to attempt to cause the meter to over-read, in order to increase the payment receivable.

Both the test results and practical considerations clearly indicate that the simplest and most effective means of causing the heat meter to register an incorrect reading (whether over or under) is to tamper with the temperature sensors. The effect of changing the location or the fixing method of the temperature sensors has considerably more effect on the energy recorded (potentially 30 to 60% energy error for improperly installed sensors) than any disturbance to the water flow, with the exception of the introduction of air/gas into the flow for ultrasonic meters. The latter, however, has the effect of causing a nil or low reading, which would not be a concern for the RHI. From a practical viewpoint, tampering with the location of the temperature sensors is a lot simpler than making changes to the flow pipework, and is possibly easier to conceal as well. Even the method of sealing or locking the installed temperature sensors is possibly not as tamperproof as the traditional methods of locking a meter body (gas, electric, or heat). A typical installation is shown in Figure 53.

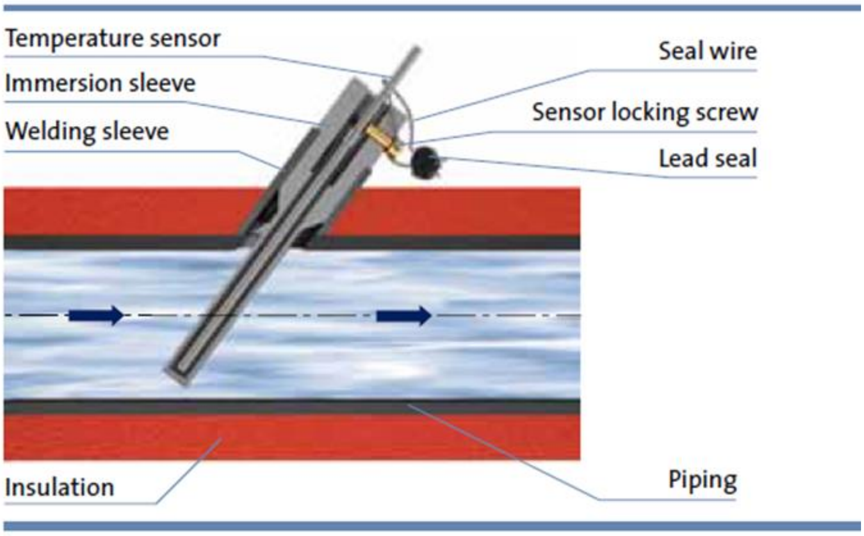


Figure 53: Typical temperature sensor installation showing locking screw

On the other hand, when one is presented with a system where payment is made on the basis of the amount of heat generated, and the incentive in the term RHI implies that the payment made is higher than the cost of generation of the renewable heat, it is perhaps easier, safer, and more logical to devise a method of generating more heat to increase payments receivable, rather than tamper with the meter installation. This could take the form of increasing the operating time or the temperature set points to make the equipment work longer and harder with the knowledge that every kW of heat generated represented an increase in revenue to the owner of the equipment. This form of fraud cannot be identified by testing, calibration, or inspection of the meter installation, but is generally managed by establishing a two tier payment structure where heat generated over a defined threshold is reimbursed at a lower rate.

Financial implications of meter inaccuracy

The RHI requirements for meters to meet the performance criteria of MID Class 2 for non-domestic installation and MID Class 3 for domestic installations establish boundary limits for the expected measurement errors. It is understood that measurement errors for installed meters can go beyond these limits, whether as a result of incorrect installation, system effects, or simply through a deterioration of meter performance with time.

This research has demonstrated that incorrect installation of the flow sensor and system effects have little significant effects on meter accuracy, whereas incorrect installation of the temperature sensor pair can have a significant effect.

The implementation of a recalibration procedure is based on the management of the risk of inaccuracy. Meter replacement and meter calibration also have financial implications and the replacement or recalibration of meters arbitrarily could be challenged as irresponsible use of resources.

The historical statistics generated by the RHI payment data could also provide pointers or indicators to identify trends in meter accuracy, with the main question being whether meters tend to over-read or under-read with increasing operating hours.

It should be possible to establish a simple economic model to determine the cost implications of recalibration intervals and deterioration in performance, and to use this as a background to determine an optimal strategy, but this was not within the scope of this research. Unfortunately it might be necessary to estimate deterioration in performance since actual data for different meter types has not been published.

Definition of a protocol for recalibration

The main scope for recalibration of heat meters in the EU is generally in relation to the billing of services from district heating companies, and the responsibility for checking, recalibrating, and/or replacing is generally placed on the district heating supplier.

The main context of this work is the use of heat meters for the measurement of renewable heat generation in connection with the RHI. Hence while most recalibration schemes are set up and monitored to ensure that the consumer is not overbilled by the district heating supplier, the scenario here is to ensure that the consumer is not overpaid or over reimbursed by the state for the renewable heat generated by the installation.

There are three clearly identifiable alternatives to the issue of meter reliability over time, namely:

1. Replacement of meters after a fixed time interval
2. Recalibration of meters after a fixed time interval
3. Statistical control system

The closest national parallel to this issue is the requirement of accuracy of measurement of domestic electricity and gas meters.

The Industry Metering Advisory Group (IMAG) submitted a proposal for the in-service accuracy monitoring of domestic gas and electricity meters in the UK following the introduction of the MID and this report was accepted by Ofgem in 2008. The proposal set out a methodology based on sample testing whereby energy suppliers and asset owners can demonstrate that they are fulfilling their statutory obligations to keep their meter populations in proper order for correctly registering the quantities of gas and electricity consumed. The objective of the proposal is to provide an approach that can be adopted by all, regardless of the meter population size. However, in order to provide measures which are meaningful, the sampling must be undertaken in a controlled manner, and include the declaration of a lot or batch, the selection of an appropriate sample size, and a methodology for the testing and interpretation of the results. The IMAG recommendation is based on the requirements of ISO 3951 Sampling procedures for inspection by variables (BS 6002). The percentage of non-conforming meters in the samples is used to define the quality of the samples and of the specific population under test.

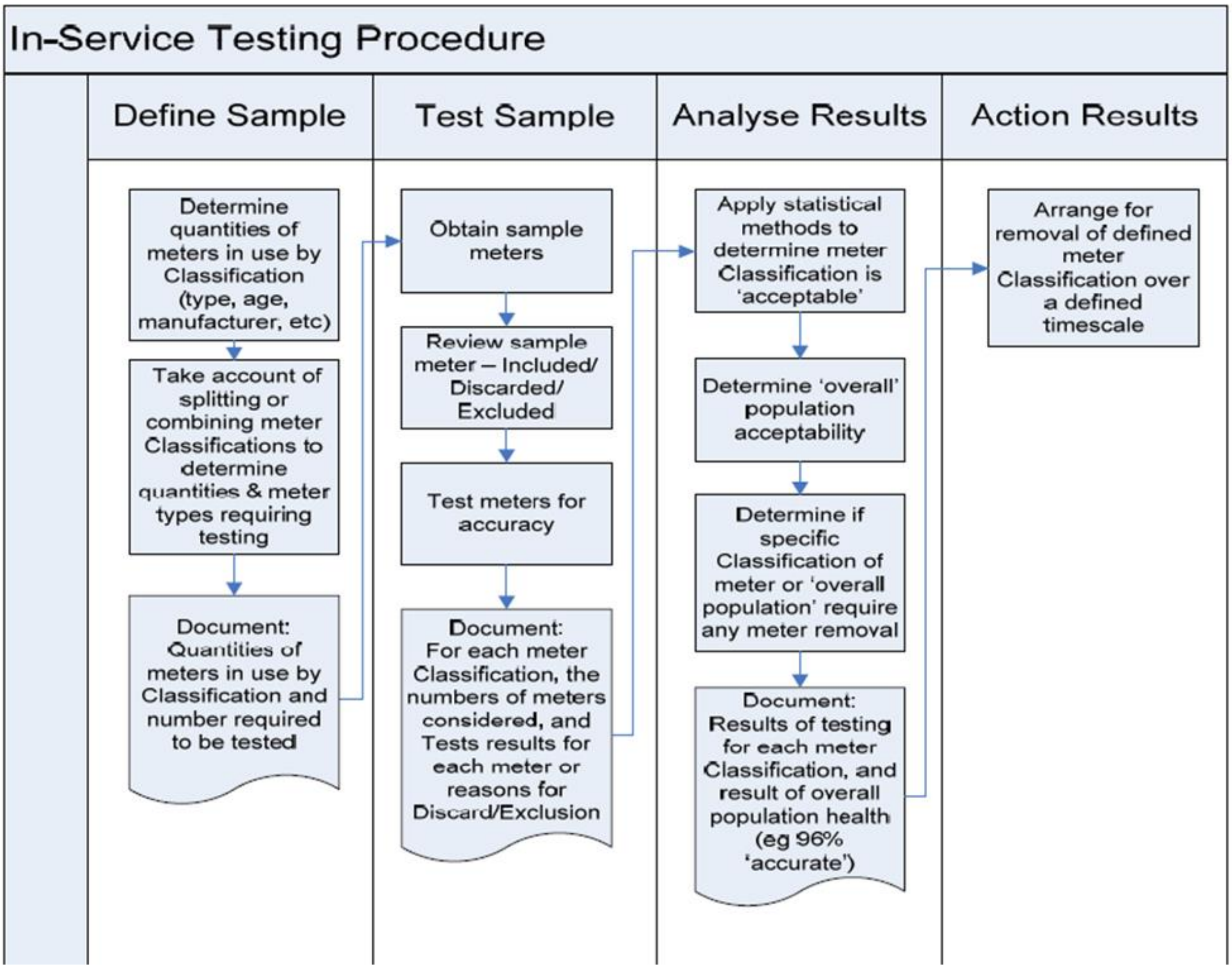


Figure 54: Procedure for ensuring compliance for domestic gas and electricity meters

In-service testing by sampling should only be carried out on homogenous populations of meters, i.e. meters of the same characteristics, namely:

- Manufacturer
- Type or model
- Capacity/ Rating
- Year of Manufacture
- Number of the EC type examination certificate or the EC design examination certificate

Meters which share common characteristics may be combined to form a single population and in the case of meters of the same type, a number of years' manufacture, up to but not exceeding five years, may be combined to form a single super-population. This has been shown to be acceptable for electricity meters but not for gas meters. Meters which have been repaired without disturbing the metrological seal are considered to be part of the original population to which they belonged before repair.

The time intervals for in-service monitoring of gas meters are every three years whereas for electricity meters the first assessment is after eight years and then every five years thereafter. The sampling criterion for meter populations is given in Table 24. It is suggested that populations smaller than 1201 are not economic for the testing of domestic type meters.

Population by type and year	Sample size
1,201 to 3,200	50
3,201 to 10,000	75
10,001 to 35,000	700
35,001 to 150,000	150
>150,000	200

Table 24: Sampling Criteria for meter population

No equivalent procedure could be identified in the UK for the in-service testing of water meters, which are technically the most aligned to heat meters. The IMAG in-service testing group assumes a 20 year life for gas meters and a 23 year life for electricity meters, International studies on the economically optimal point for the replacement of water meters generally define the lifetime of cold water meters are between 15 to 30 years.

When considering a protocol of the recalibration of heat meters in the UK, it would be preferable if the recalibration could be carried out in the field, although the practical aspects of field recalibration require further investigation. Although the installed quantities of heat meters are presently low, it would definitely be preferable and more cost effective to organise a sampling procedure rather than to have a system were all meters had to be tested. A sampling procedure for field recalibration would eliminate the problem of replacement logistics related to laboratory based recalibration protocols. Table 24 does not provide any clear basis or justification for the variety of certificate validation periods but on the basis of the mature systems implemented in Denmark, Sweden, and Germany, it seems reasonable to consider a period of between five to six years between recalibration. The implementation of a sampling procedure implies that more frequent recalibration (five to six years as opposed to the current ten year period) is less onerous, in that it would result in reduced quantities of meters for recalibration.

Accuracy for research projects

It is understood that research projects require a higher level of accuracy than metering for the RHI. Clearly this research has demonstrated that in order to attain a high level of accuracy the installation of both the flow and the temperature sensors is at least as important as the meter class. Where high levels of accuracy are required, it would be preferable to carry out some form of calibration in situ to ensure performance as installed.

It is also important to give due consideration to the method of data collection. Most meters offer the facility of both pulse outputs and M-Bus (see outline provided in section *Data interfacing*). Whilst the pulsed output is the simplest to manage, the resolution of the meter must be matched to the expected load, since a meter which has too high a resolution can 'lose' pulses when high energy values are read, and a meter which has too low a resolution will not be able to provide accurate readings over short time intervals. The M-Bus communication offers greater flexibility but involves a more complex and lengthy setting up procedure.

Summary

The purpose of both the test program and the desk based research was to provide a better understanding of the following:

- A metering specification for the RHI
- A metering specification for DECC research projects
- The financial implications of installation effects and meter inaccuracy
- The optimal recalibration period for installed meters

Primarily on the basis of the test program, it is clear that the current RHI requirement for MID class 2 meters is appropriate for commercial applications, and the requirement for MID class 3 meters is appropriate for domestic applications. It was found that the various meter types tested are generally robust even when not installed in accordance with the manufacturers' recommendations, with a few notable exceptions such as the effect of air entrainment on ultrasonic type meters. The main criterion to ensure that the accuracy of installed meters remains within the range of the MID class is the type and installation method of the temperature sensors. Temperature sensors must be installed in the fluid flow (using pockets or 'Binder' type points) for accurate energy measurement.

Metering for DECC research projects requires a higher level of accuracy than the RHI and apart from the installation of temperature sensors mentioned above, the main factors to be considered are the resolution of the meter and the method of data collection. It is recommended that wherever possible, in situ calibration be carried out for DECC research projects.

Due to the above mentioned robustness of the meter types tested, the main installation effect to be considered when checking for meter inaccuracy, whether intentional (fraud) or through negligence, is the type and method of installation of the temperature sensor pair.

The optimal recalibration period for installed meters is difficult to determine arbitrarily, although it appears that a number of EU states have done this (see Table 23). There is however no justification for the requirement for a recalibration period and this has been confirmed by Izdebski (2015). The logical approach is to consider a statistical sampling exercise which would allow flexibility to determine the recalibration period based on the outcomes of the sample testing.

Conclusions and recommendations

The overall purpose of this research is the evaluation of heat meter accuracy under conditions where the meters have been installed incorrectly, and to obtain evidence of heat meter performance under these conditions. The objective of the research was the development of appropriate metering specifications for both the RHI and DECC research projects.

This research project consists of an analysis of previous work carried out on heat meter accuracy, a review of relevant findings from on-going metering projects and existing research, laboratory testing of a representative sample of new heat meters, and additional desk-based research investigating the different procedures in place in other EU states for testing and recalibration of used heat meters.

The conclusions drawn below are based on the outcome of this work and on professional experience of heat meter installation and auditing.

Heat Meter Accuracy

Heat meter accuracy is dependent upon:

- The type of meter and the technology employed for flow measurement, temperature measurement, and energy calculation as appropriate;
- The installation effects including various site conditions;
- The system effects including the choice of the measurement point, appropriate sizing of the meter, selection of a sampling rate, etc.

The scope of heat meter accuracy within the RHI is to ensure that (renewable) heat is measured robustly and effectively such that the RHI only pays an incentive for the correct quantity of heat generated from a renewable source.

Background and regulatory framework

It is appropriate to recapitulate that heat meters are devices for the measurement of thermal energy (heat). In a heating system the thermal energy is directly proportional to the product of the fluid flow rate and the fluid temperature difference. The heat meter consists of a flow measurement device, a pair of temperature sensors to measure the temperature difference, and a calculator to determine the thermal energy on the basis of the inputs from the flow and temperature difference.

Heat meters are not subject to legal control in the UK. However the RHI regulations define the minimum standards that heat meters must meet in order for measurement of the amount of renewable heat that is eligible for RHI payments. The non-domestic RHI scheme regulations stipulate that heat metering must comply with the specific requirements listed in Annex MI-004 to the MID and fall within accuracy class 2 as defined in the Directive whilst the domestic RHI scheme regulations stipulate that metering should meet the requirements for accuracy class 3

The maximum permissible errors (MPEs) differ between the accuracy classes. Energy measurement by heat meters is carried out by processing the results of flow measurement and temperature measurement and consequently the MID allocates different MPEs to each of the three components of the heat meter; the flow measurement device, the temperature difference measurement sensors, and the calculator or processor. The MPE of the heat meter is defined as the sum of the MPE of the three components. There is no variance between classes for the MPE of the temperature difference measurement or the calculator, so the permissible variation in accuracy between the different MID classes is solely related to the accuracy of the flow measurement device. Whilst the MPE of the flow sensor is capped at 5% for both Class 2 and Class 3 meters, in practical terms there is approximately a 1% difference between the MPE for flow measurement of Class 2 and Class 3 meters over normal operating conditions as reproduced by the laboratory test program.

Conclusions - Accuracy

The data generated by the laboratory testing clearly demonstrated that the temperature measurement errors were minimal for correctly installed sensors, and well within the MID limits.

On the other hand, even when the flow meters were correctly installed, the flow measurement errors did not always fall within the appropriate MID MPE limits.

The accuracy of the calculator is determined by the appropriate configuration of the calculator to the system being measured, and this is not affected in any other way by the method of installation.

Overall, however, the energy measurement for the new meters correctly installed was within the MID class limits, which vary according to the operating conditions at time of measurement. Over the majority of tests and operating conditions of the laboratory test program, the overall MID MPE for the heat meters was between 4 and 7%.

To improve the accuracy of the flow measurement within a specific system, it is necessary to calibrate the flow sensor to the system. Although theoretically this would also apply to the accuracy of the temperature measurement, the accuracy of calibration of the temperature sensors by the manufacturers (see Table 16) is already of the order of 0.1°C, and hence it is only in systems with very low operating temperature differences (< 3°C) that recalibration of the temperature sensors could be useful in improving accuracy.

Heat Meter Installation Effects on Accuracy

Manufacturers test their meters to ensure that they comply with the MID class accuracy requirements but they also establish installation parameter boundaries which have to be met. No linkage between poor or non-compliant installation and inaccuracy is supplied by manufacturers. Conditions in the field do not always allow the facility of installation in accordance with manufacturers' recommendations, and may deviate by a small or larger degree. The main scope of the test program was the identification and quantification of heat meter installation effects and heating system set-up effects on heat meter accuracy.

Background and previous research

With some variation according to meter type, heat meter error can be increased by valves and bends disturbing the flow as well as by electromagnetic noise, acoustic noise and pulsations, and particles, droplets and bubbles, system dirt, etc. Previous research (for example AECOM, 2013) and the opinion of industry experts generally acknowledge that even with all the experimentation and research carried out in connection with installation effects they are still not well understood. The test program devised and executed within the scope of this work can be classified into the following broad categories:

- Calibration tests to establish the heat meter performance in ‘ideal’ installation conditions.
- Tests carried out with disturbances to the fluid flow.
- Tests carried out with ‘sub-standard’ temperature sensor installation.

Findings

A number of tests were carried out with different configurations for disturbance to the fluid flow including bends, proximity to the pump, and incorrect orientation of the meter. The configuration with the most significant effect was air entrainment within the fluid flow for the ultrasonic type meters. This caused the meters to stop reading, even at the lowest values of air entrainment tested. Contrary to our expectations, the other tests carried out with flow disturbances did not generate significant errors in the flow measurement, even when a combination of installation errors was tested. In our opinion it appears that the new meters under test are of robust design and the manufacturers’ parameters for a correct installation have been established within a considerable safety margin. Also contrary to our expectations, comparison of the results between the different meter types tested does not identify any specific trends or differences in accuracy between the flow measurement technologies employed. Individual manufacturers claim specific advantages for the various technologies incorporated in their respective meters but no significant variation between meter types could be identified, except in very specific circumstances. This uniformity of performance between meter types, and resilience to incorrect installation, is specific to the flow measurement performance of new meters in laboratory conditions. It is quite possible that long term installation in field conditions could cause a drop-off in the accuracy of the flow measurement that could vary between meter types dependent on the installation configuration. The main source of data for this is the substantial amount of historical data on the use of mechanical or rotary type meters for cold water metering (Arregui, 2005 and 2007).

The tests on the temperature sensor installation were sub-divided into two categories, sensors inserted into the fluid flow (pockets or ‘Binder’ points) and sensors strapped on to the outside of the pipe (standard or custom designed strap-on sensors). These tests were carried out in steady state and transient conditions. Here the data showed that for sensors inserted into the fluid flow there was very little sensitivity to the various installation configurations tested, with little or no significant differences recorded between pockets and ‘Binder’ points, insulated or uninsulated measurement points, and the use of thermal paste in pockets. On the other hand, sensors strapped on the outside of the pipe showed great sensitivity to installation variation, with the potential for errors of the order of 30% or more. It was noted that it is particularly difficult to ensure good thermal contact between the sensor and the pipe, even where custom designed strap-on sensors were used. Significant errors (up to 60%) were noted where the sensor installation was not homogenous, i.e. the two temperature sensors were not installed in the same way.

Although the AECOM (2013) tests were different in range and somewhat more limited in scope, there are a number of parallel findings which it is appropriate to highlight at this stage. The AECOM tests also resulted in one (turbine meter) out of the three meters tested giving flow readings which were outside the MID Class requirements, and AECOM assumed that this was due to calibration drift. AECOM reported anecdotal evidence on the effect of air entrainment and dirt but could not identify any back-up for this evidence. The results from this research indicate that the effects of dirt and air entrainment are less than the values quoted in the AECOM report. The AECOM laboratory tests on flow disturbance provided results similar to the tests in this report, in that the range of errors reported for the less varied flow disturbance tests carried out, in the main part, do not show any significant errors outside the MID Class 2 error bands. AECOM also report in their conclusions that an unreported test of strap on temperature probes resulted in large measurement errors.

Conclusions – Installation Effects

Figure 58 summarises the findings of the test program in relation to the effect of installation errors. Meter accuracy depends on three components, the flow sensor, the pair of temperature sensors, and the calculation device.

There are a variety of approaches to flow measurement, and these account for the inherent differences between the meters tested. The test program indicated that incorrect installation of the meters generally did not result in large measurement errors of the flow sensor. However it also showed that there are inherent difficulties in reducing measurement errors of the flow sensor, even when correctly installed.

On the other hand, it was found that the accuracy of measurement of the temperature difference is very high, but poor installation procedures can generate large measurement errors.

The accuracy of measurement of the calculator is also very high, but this is dependent on the proper configuration of the instrument.

It is important to note that the accuracy of the meter is not constant or fixed, but varies according to the flow rate and the temperature difference. This is taken into account by the MID which defines the MPEs in relation to these parameters. Selection of the appropriately sized meter to match the actual operating conditions can be significant in reducing measurement errors.

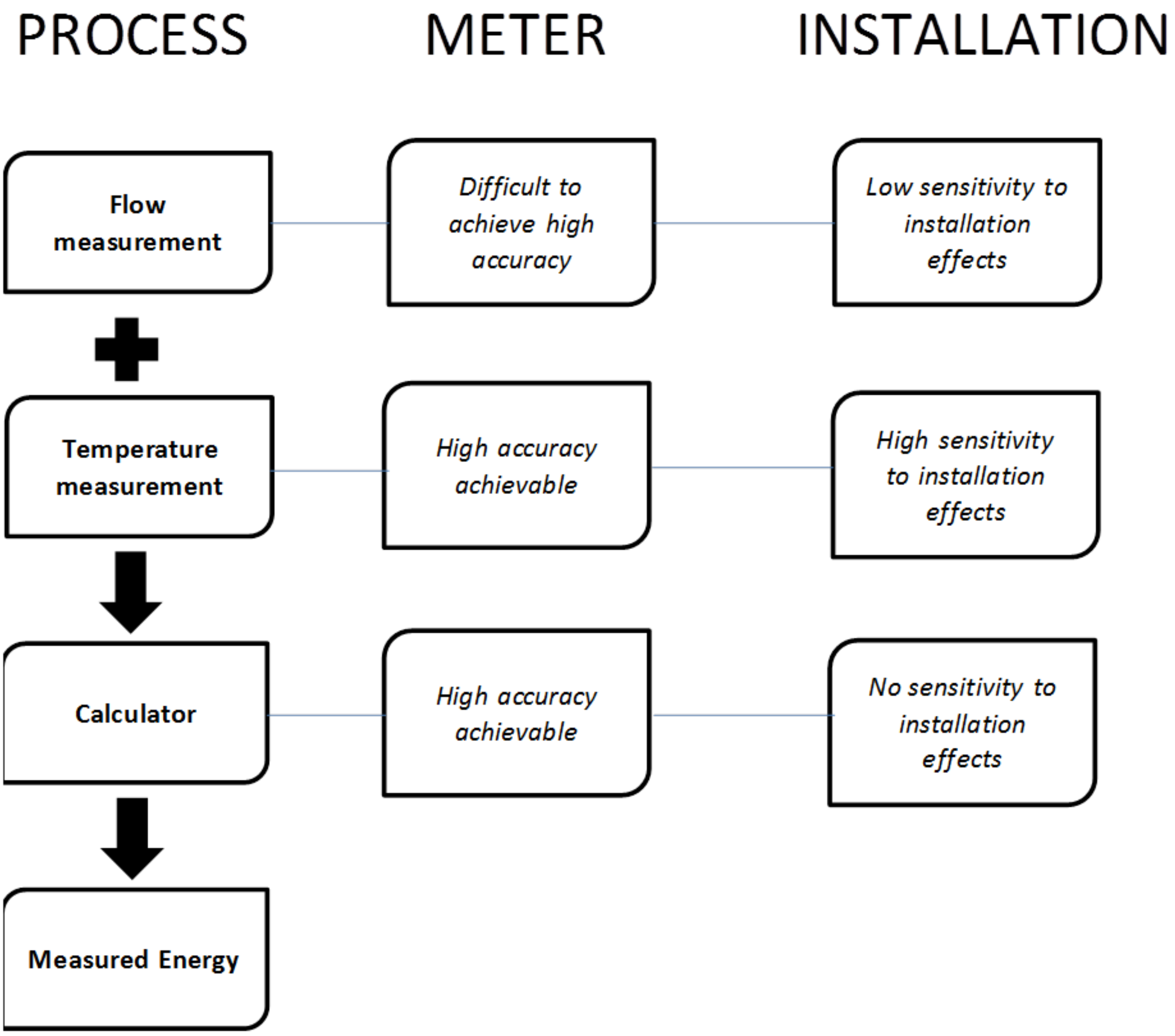


Figure 55: Schematic summary of findings from test program

Metering system set-up and other parameters

A number of heating system characteristics could potentially have an impact on the accuracy of measurement of heat meters. Potential sources of error which did not form part of the analysis carried out during this project include the effect of different types of pipe material, incorrect meter sizing, characteristics of the heating system being measured, and the build-up of lime scale within the system,

An analysis of the combined effect of different installation errors and the frequency of their occurrence, based on the available audit data, has been reported in report section *Estimating the impact of errors in the field*.

The relationship between installation errors and the limited possibilities for fraud or “gaming” have been outlined in report section *Heat metering installation arrangement, tampering and fraud* of this report. Apart from the priority to be given to the temperature sensor installation, as mentioned in report section *Heat Meter Accuracy*, the monitoring of the historical performance of the metered system can also be used to highlight meters which could require additional investigation or recalibration.

The effect of metering set-up errors such as errors associated with the system fluid glycol concentration differing from the design value and hence from the meter calibration have been tested in the laboratory and found to fall within the expected values as calculated.

One outcome arising from the laboratory test program was the possibility of measurement errors arising relating to the frequency of measurement (sampling rate), the resolution of measurement, and the method of data collection (pulses, M-Bus, etc.). Issues relating to the resolution of energy values displayed by heat meters and the resolution of energy pulse outputs have been outlined in report section *Data interfacing*. This is of particular relevance to metering research projects and re-iterates the importance of in-situ calibration of heat metering for any application where accuracy is critical.

The tests in an old dirty house heating system, whilst still on-going, have showed significantly different susceptibility to dirt between the meters. There was also a marked difference between the two ultrasonic heat meters at the start of the test when the system had high levels of dirt and also air. One ultrasonic heat meter displayed a large over reading of energy and flow and the vortex showed a large under reading. The other heat meters including the other ultrasonic meter, the rotary meter and the reference electromagnetic flow meter initially showed much less sensitivity to dirt. However, later on in the test the vortex and rotary meters showed a gradual continuous decline in accuracy whereas the accuracy of the two ultrasonic meters stabilised.

Metering accuracy over time

There is very limited data available defining the long term accuracy of heat metering, and the available data is generally restricted to specific meter types and makes. Possibly as an outcome of the MID, a number of European states have defined the period of validity for heat meter calibration and this appears to vary between two and ten years (see Table 23). The practicality of an approach where heat meters have to be either removed for testing or tested in situ after a fixed time period, especially at the lower end of the range (e.g. every three years) is somewhat questionable. EU states with a well-developed district heating network, and hence a well-developed heat metering network, have adopted statistical quality control systems to check the performance of heat meters after five to six years of installation, and use this data to confirm or otherwise that metering accuracy is being maintained. On the basis of the published data for ultrasonic heat meters, and the limited test data available from this work on used vortex heat meters, it does appear that metering accuracy is maintained over time for these meter types. Without specific experimental evidence on heat meters, both practical considerations and published data for water flow meters indicate that the performance of mechanical multi-jet meters can be expected to deteriorate with time.

The implementation of a statistical quality control system for heat meters inherently implies that a smaller quantity of meters need to be tested on an annual basis, and this allows the flexibility of shortening the recalibration period without substantial cost implications.

The practical difficulty in the implementation of a statistical quality control system for heat metering in the UK is related to the fact that such systems are most cost effective when the heat meter population consists of large batches of similar meters. It does seem, however, that the installed heat meter database consists of small quantities of different meter types.

Summary

Heat meter accuracy is dependent on the accuracy of the three components required for thermal energy measurement, the flow meter, the temperature sensor pair, and the calculator. The test results show that it is difficult for the installed flow meter to meet the MID accuracy levels, but this component is relatively resilient to incorrect installation. On the other hand, accurate measurement of temperature difference is achieved by all flow meter types tested, but the proper installation of the temperature sensors in the fluid flow is critical. The calculator can output precise results if the meter is configured correctly for the actual system fluid and components. The combined error of the heat meter installed correctly can meet the MID accuracy levels even when the flow meter is at the limit of accuracy since this is compensated for by the precision of the temperature sensors and the calculator.

Accuracy over time

The technology and materials used for the temperature measurement and the calculator are unlikely to demonstrate deterioration over time. Experience with similar temperature sensors in different applications has shown that their accuracy is maintained. Although one set of temperature sensors actually failed during prolonged exposure to dirt (Appendix G) this was a total failure and not a deterioration over time. The calculator module is microprocessor based and the accuracy of the calculation cannot deteriorate, although there is the possibility that changes in system fluid or setup might require reconfiguration. The meter component which is most liable to demonstrate a decrease in the accuracy of measurement over time is the flow meter. This is the component which may contain moving parts subject to wear and tear, which is exposed to corrosion and/or erosion by the system fluid, and which may experience the build-up of dirt or limescale with time. The different meter types are likely to demonstrate different susceptibilities to these effects, and further long-term research is necessary to obtain a better understanding of the possible decrease in accuracy of heat metering over time.

Meter specification for the RHI

The current specification for the RHI is considered to be suitable for purpose. The resilience of the meters tested to the majority of installation scenarios indicates that new meters installed in the field are expected to output results within the MID accuracy limits. The main emphasis to be made is on the correct installation of the temperature sensors, and the use of strap-on sensors should not be allowed. Further research is required to better understand the effects of changes in the system configuration and/or deterioration of the meter performance over time. In the case of systems where the logging or remote reading of the meter is required, it is also important to carefully select the resolution of the meter output, since too high a resolution might result in the loss of data.

Meter specification for DECC research projects

Metering for research projects requires a higher level of accuracy but this is unlikely to be achieved by improving the specification of the meter itself. Improving the level of accuracy is dependent on the installation and the most appropriate method of ensuring this is to calibrate the meter in situ. Of course this is in addition to the requirements mentioned above for the RHI. The use of the M-Bus protocol for data collection is also recommended for DECC research projects since this can provide a better level of data accuracy and functionality.

Recommended time period for recalibration

It is difficult to establish a time period over which heat meters can be expected to maintain the desired level of accuracy. There does not seem to be any scientific basis for this, and very limited data has been published by a single manufacturer. The logical solution is to implement a statistical sampling of installed meters and to use this data to decide on an annual basis whether the batch sampled is still within the desired levels or not. A long term field testing exercise on a small number of meters would also be useful to determine the time period between sampling.

Recommendations for future work

The laboratory testing and the research carried out on this project, together with feedback from DECC, enabled the identification of areas where further research could provide a useful contribution to knowledge of heat meter applications.

Two principal categories where available knowledge is limited and where further research could be of practical value are the following:

a) It has been suggested that in order to achieve a defined level of accuracy for research work, in situ calibration of the heat metering installation is essential. The development of a protocol for in situ calibration, together with a practical field trial on a small number of sites, would be useful for both research work as well as for testing the accuracy of installed heat meters over time. It might also be possible to use the data obtained from in situ calibration over time to justify extending (or shortening as the case may be) the period of time before recalibration of a heat meter is necessary.

b) Independently of the first proposal, there is very limited data available on the long term accuracy of heat metering installation and it is considered that it could be useful to have a small number of test sites or installations where monitoring of the heat meter performance is carried out over a longer term than the current test program. This could possibly enable the identification of operational parameters (such as dirt build up, wear and tear, lime scale, etc.) that affect meter accuracy over time, and provide a timeline to better understand when these factors become significant in relation to meter accuracy. The testing carried out and reported in Appendix G confirmed that these parameters have a bearing on meter accuracy over time. However the short time frame and the accelerated pace of these tests implies that the results are not sufficient to identify over what time duration do these parameters have a significant effect on meter accuracy in actual operation.

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Appendix A Heat meter accuracy testing – summary of test programme

Table 26 provides a breakdown of the project specific objectives expanded to two additional levels of detail.

Level 1	*Level 2*	*Level 3*
Heat meter accuracy: • Acceptable error levels for policy work • Acceptable error levels for DECC research projects • Relative importance of meter accuracy versus correct installation on overall accuracy	**Heat meter installation effects**	• Types of installation error, to include: o Incomplete pipe insulation o Heat meter on wrong pipe o Heat meter not calibrated for glycol o Incorrect heat meter sizing o Heat meter orientation wrong o Temperature probe installation (e.g. strap-on) • Effect of meter type and model on the above • How common are the above installation errors • Effect of installation errors & sensitivity of the extent of the error • Effect of combining installation errors • Effect of pipe type • Exogenous/external factors • Impact of installation errors on potential for fraud
	Heating system set-up	• Which heating system arrangement have an effect on heat meter readings, to include: o Gas bubbles o Dirt in heating system water o Low water static pressure • Size of resulting measurement errors • What factors affect the extent of the errors • Effect of cumulative errors, including heating system and installation errors
	Variation in heat meter accuracy over time	• How does meter accuracy decline over time for different meter types & models • What other factors that affect accuracy decline (worsen) over time • How reliable are different types of heat meter • How often do meters require recalibration o Does this vary by meter type o Is the current DECC 10 year recalibration correct • How often is maintenance/flushing/bleeding etc. needed to maintain accuracy

Table 25: Summary of specific project objectives

Appendix B Test Strategy and Prioritisation

TEST STRATEGY AND PRIORITISATION

Classification	TEMPERATURE			FLOW						CALCULATOR		OTHER
Description	Poor mounting	Not paired	Poor location	Disturbances	Air / dirt	Orientation	Location	Flow obstruction	Incorrect location	Glycol conc	Water temp	Transience
Likelihood of occurrence	25%	5%	25%	50%	50%	25%	5%	5%	5%	25%	10%	25%
Expected magnitude of error												
Effect of error on reliability of meter over time												
Expected magnitude when combined with other errors												
Overall test priority												

Colour code denotes level of priority:

- High priority
- Medium priority
- Low priority

NOTES

1. Likelihood of occurrence is based on the data from the RHI and RHPP surveys (limited due to small size of survey) and expert judgement
2. No distinction is being made for the different meter types at this stage. The test program will be used to identify and highlight any variances in performance and sensitivity to error between meter types. It is not expected that interpolation of any sort can be carried out between different

3. Tests on installation scenarios which have a low (green) expected magnitude of error (whether standalone or combined) are not considered for inclusion in the test program, except for the glycol concentration tests.
4. The expected magnitude of error and the expected magnitude when combined with other errors can be related to the value of the maximum

Appendix C Heat meter tests

Heat meters to be tested

The specifications called for lab testing of the four most common types of flow measurement devices, with testing of more than one meter of the same type.

Tests are to be carried out at the reference conditions for the test laboratory, namely

- Range of ambient temperature 15°C to 35°C
- Range of relative humidity 25% to 75%
- Range of ambient air pressure 86 kPa to 106 kPa

The actual temperature and relative humidity within the specified range shall not vary by more than ±2.5°C and ±5 percentage points respectively during the period of one measurement.

New heat meters

The analysis of installed heat meters registered in the RHI database indicated that over 60% of the installed meters are of the ultrasonic type, with a further 17% are of the Vortex type. The remainder of the market (under 20%) is fragmented amongst over 20 different brands. No electromagnetic type meters could be clearly identified from the database. The calibrated flow meters used by BRE are of the electromagnetic type and hence it is being proposed to exclude the electromagnetic type meters from the testing of new heat meters and to test two brands of ultrasonic meters instead, these being more representative of the installed stock. The dimensions selected are representative of the non-domestic market. The mechanical type meters referred to as turbine meters in the tender specification have been replaced by multi jet type meters in the market and hence these have been selected for testing.

It should be pointed out that although the Metering and Monitoring Service Packages Technical Supplement published by DECC (12th July 2013) generally recommends that heat meters should have resolution of one pulse per Watt hour, most suppliers are offering a resolution of one pulse per ten kilowatt hour.

2 samples of each type & size	28mm	40mm
A	X	X
B	X	X
C	X	
D	X	

Table 26: New heat meters tested

Test set 1 – Accuracy at different water temperatures and flow rates

Test Rig Number 1 – 28 mm Test Rig Number 2 – 40 mm Fixed temperature difference between the flow and return sensors - both sensors in a calibration water bath to give ΔT. Water will be circulated at constant temperature. BRE instruments: calibrated reference flow meter and immersion temperature sensors. Scope: To demonstrate accuracy of flow meter is not affected by temperature, flow rate, meter type, etc.

Assess accuracy of each heat meter at the limits of the operating flow rate range and temperature range as determined by practical application limits to assess MID compliance under these conditions.

Two of each type of new heat meter will be tested to assess any variability. If there is a large discrepancy between the two units then another sample will be obtained and tested. In the event of a large discrepancy being found the manufacturer will be contacted and asked to comment.

Note: test rig 1 will also be used for assessment of the effect of temperature sensor mounting (should allow space for both sensors to be mounted on the pipe).

Heat meter	**Temperature differences**		
Test 2 samples of each type & size	30°C/33°C	40°C/45°C	55°C/65°C
Type A (28 mm diameter) Flow rate in l/s	1	0.05 0.5 1 1.5 2	1
Type A (40 mm diameter) Flow rate in l/s		0.5 1.4 2.8 4.2 5.6	
Type B (28 mm diameter) Flow rate in l/s	1	0.05 0.5 1 1.5 2	1
Type B (40 mm diameter) Flow rate in l/s		0.5 1.4 2.8 4.2 5.6	
Type C (28 mm diameter) Flow rate in l/s	1	0.05 0.5 1 1.5 2	1
Type D (28 mm diameter) Flow rate in l/s	1	0.05 0.5 1 1.5 2	1
Old heat meters (Type B) Flow rate in l/s		0.05 1.4 2.8 4.2 5.6	

Note: Type A and B are the top two most widely used meter types for non-domestic applications.

(Indicative number of tests – 116 including an allowance for six used heat meters)

Table 27: Assessment of flow meter accuracy under different operating conditions

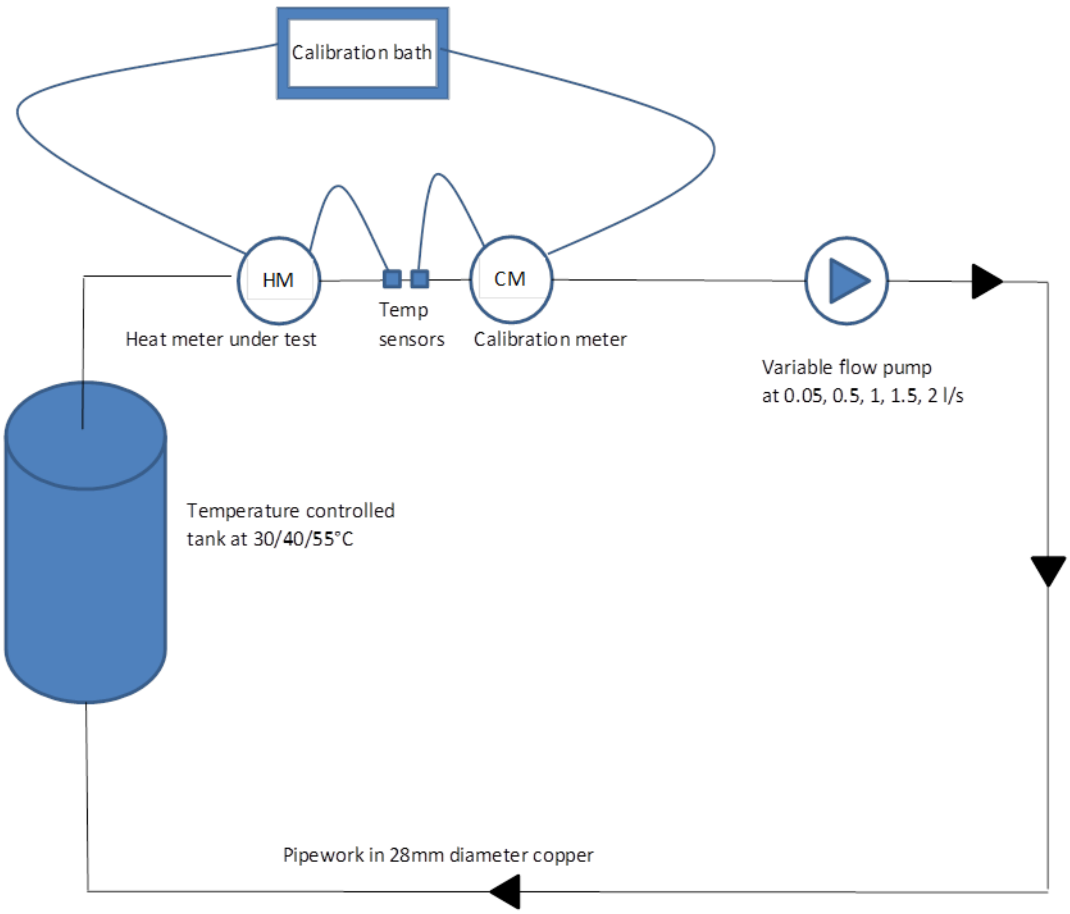


Figure 56: Line drawing of Test Rig Number 1

Test set 2 – effect of different installation and system operational characteristics on accuracy

Test Rig Number 3 –28 mm

As for test rig 1 with pipework alterations for installation and system characteristics

Scope: To determine effect of different installation characteristics on meter accuracy,

Test no	Temperature difference fixed 30°C/33°C (Repeat at 3 flow rates 0.5, 1, 1.5 l/s)	Type A to D (4 meters – 1 sample each)
1	Heat meter on positive side of pump.	✓
2	Heat meter on negative side of pump.	✓
3	90° bend, heat meter on positive side of pump at two distances from bend	✓
4	Two off 90° bends, heat meter on positive side of pump at two distances from bend	✓
5	Two off 90° bends, heat meter on negative side of pump at two distances from bend	✓
6	Air entrained in flow, heat meter on positive side of pump.	✓
7	Air entrained in flow, heat meter on negative side of pump.	✓
8	Incorrect orientation A and B	✓
9	Incorrect orientation A with 90° bend on inlet	✓
10	Incorrect orientation A and B with air entrained in flow	✓
12	Incorrect orientation B with 90° bend on inlet	✓

(Indicative number of tests – 192)

Table 28: Assessment of sensitivity to installation and system characteristics

Test set 3 – effect of changes in fluid (glycol antifreeze protection) on accuracy

Test Rig Number 1 – 28mm BRE instruments: calibrated reference flow meter and immersion temperature sensors. Note prior to test reference flow meter is recalibrated for glycol using timed discharge into measuring tank. Scope: To determine the effect of using the incorrect fluid (glycol) in a meter which has been set up for water.

Heat meter (1 sample of each)	Water	Glycol and water mix (for -20C protection) (Repeat at two flow rates 0.5 & 1 l/s and two glycol concentrations 10% & 30%)
Type A	✓	✓
Type B	✓	✓
Type C	✓	✓
Type D	✓	✓

Note: In all cases the meters ordered are designated for use in standard untreated water installations.

(Indicative number of tests – 20)

Table 29: Assessment of the sensitivity of heat meters to operational characteristics – glycol.

Test set 4 – effect of temperature sensor mounting type

Test Rig Number 4 – 28mm a) Assess accuracy with alternative T sensor mounting at constant ΔT b) Assess accuracy with variable ΔT (simulate heat generator cycling on/off) BRE instruments : calibrated reference flow meter, immersion temperature sensors, and power meter. Scope: To determine the effect of temperature cycling on meter accuracy

	T sensor in manufacturer supplied / approved pocket & method (with heat transfer paste/fluid)	T sensor in manufacturer supplied / approved pocket – no heat transfer paste (dry)	T sensor strap-on A – no insulation	T sensor strap-on A – taped & no insulation	T sensor strap-on A – taped & with insulation
Steady state	✓	✓	✓	✓	✓
Cycled on/off heat source	✓	✓	✓	✓	✓

(Indicative number of tests – 40)

Note: Outside the scope of the current test program but additional options for testing could include different sensor types per meter or different pipe materials.

Table 30: Assessment of temperature sensor mounting on accuracy (room T ~ 20°C)

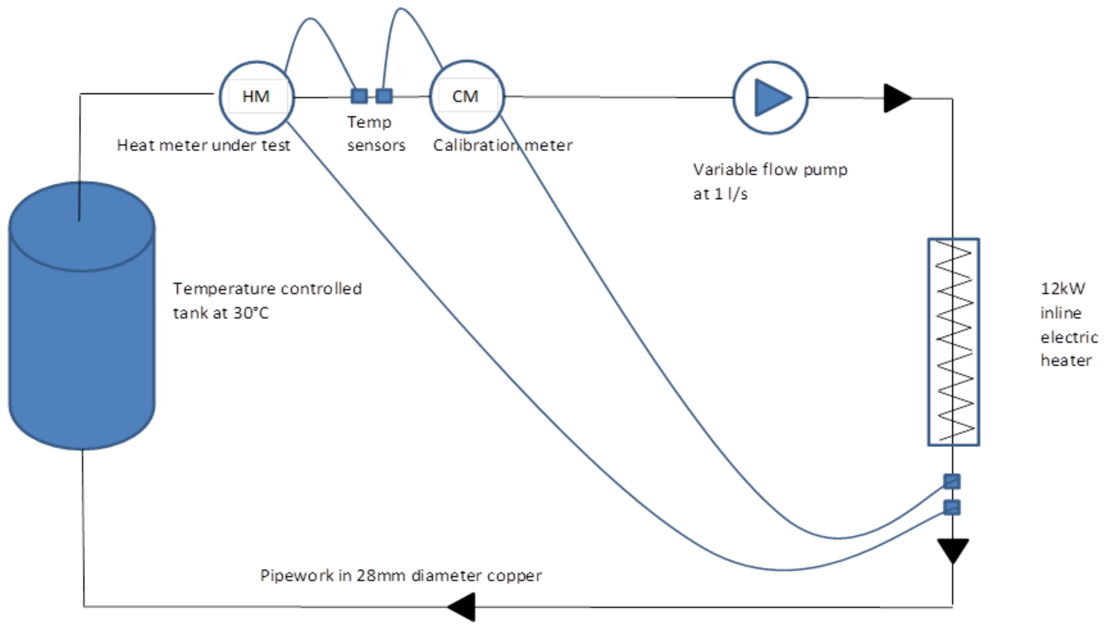


Figure 57: Line drawing of Test Rig Number 4

Test set 5 – accuracy under non-steady flow rate and temperature

Varying temperature / constant flow rate

Test rig - air source heat pump test rig ASHP transient test and all heat meters in series BRE instruments – accredited heat pump test rig Scope: To assess meter accuracy in actual heat pump operational scenario including defrost cycles

Minimum 6 hour test period / 3 defrost cycles.

Note: Four heat meter types installed in series.

(Indicative number of tests – 1 could give rise to more)

Varying flow rate / constant temperature

Test Rig Number 1 – 28mm Modulate water flow rate using inverter on pump BRE instruments – calibrated reference flow meter and immersion temperature sensors

Install all heat meters (4 types) in series in test rig. Test carried out over three hours with flow rate change every fifteen minutes, with repeated flow rate cycling to test repeatability/hysteresis.

Heat meter	Accuracy across typical operational flow range variation at 30°C/33°C
Type A	✓
Type B	✓
Type C	✓
Type D	✓

(Indicative number of tests – 1 could give rise to more)

Table 31: Assessment of accuracy under non-steady state flow rates

Test set 6 – effect of dirty water on accuracy

Test rig – heating system in BRE test house (flow boiler & power meter in place of boiler)

A sample of the heat meters will be tested in an existing 15 year old + standard radiator heating system in a BRE test house. This will expose the heat meters to realistically dirty system water. This test will be undertaken last in case dirt contamination causes damage or irreversible change in meter accuracy.

Heat meter	Influence of installation into a system known to be dirty
Type A	✓
Type B	✓
Type C	✓
Type D	✓

Table 32: Assessment of effect of dirty water on accuracy (duration as long as possible)

One of each type of the 28mm (1 inch) heat meters will be installed in series in a domestic heating system in one of the BRE test houses. The meters will be installed in a location that minimises the influence of any other characteristics of the system, upstream fittings, etc. To overcome the uncertainty that the dirt will have on our reference instruments we will instead install an electric flow boiler (set for constant heating power) and quantify the heat delivered to the water by accurately measuring the electrical energy consumed by the heater. This test will be undertaken over as long a period as is possible within the time frame of the project.

The heat output of the electric flow boiler will remain constant and therefore variations in the accuracy of any of the heat meters will be readily apparent.

If it is found that one of the meters is significantly affected by the dirt in the system, it will be removed at the end of the test, cleaned and then placed back on the accuracy test rig to determine if the change in performance is reversible through maintenance or is permanent.

(Indicative number of tests – 1 could give rise to more)

Appendix D Test Programme Analysis Charts

Footnotes to Test Programme Analysis Charts

1. Tests to be carried out to obtain a level of confidence that the meters meet the manufacturers' specifications and that the pairs of meters from the same manufacturer are actually comparable.

   Tests to be carried out over a range of flow rates to establish the effect of operating at the limits of the meter design flow rates, since some meters tend to have a higher percentage error at low flow rates. This should also give some indication on the effects of incorrect meter sizing.

2. Tests already carried out by AECOM and Arregui.

   Errors depend on meter type and flow rate.

   Tests to be repeated so as to be able to use data for cumulative error estimation.

   Heat meter orientation is known to increase the susceptibility of meters to other factors, in particular air and dirt, but this interdependancy has not been previously tested. It is important to understand and quantify the sensitivity so that the effect on the accuracy of heat meters in the field can be predicted."

3. Partial testing carried out by AECOM and Arregui.

   High likelihood of this error in practice.

   More comprehensive set of tests required especially to establish the sensitivity to the level of flow perturbation (and the effect of) slight and large deviations from the manufacturer's recommended installation.

   Tests to be used for cumulative error estimation.

   Testing to be carried out by comparison – ie one meter immediately adjacent to the disturbance with second meter installed correctly. Where significant errors are noted additional test with varying distance between meter and disturbance will be carried out to establish the sensitivity.

   Disturbances to consist of bend or bends, air/gas entrainment, pump installation in immediate vicinity, and low static pressure (cavitation risk) such as could occur when a heat meter is installed on the inlet side of the pump.

4. No prior testing but entrained air is a very common faults in heating systems.

Air is likely to affect meter types differently and magnify other installation faults, in particular incorrect orientation and possibly also proximity to bends.

5. No prior testing but dirt is a very common fault in heating systems.

   Difficult to test in a laboratory environment.

   Testing to be carried out in simulated real environment, eg test house.

   Tests to be used for initial understanding of the effect of this error.

   Likelihood of this error increases with time and has bearing on accuracy of meter over time.

6. Error can be calculated.

   No reason to include in test program.

7. Error can be calculated.

   Error value negligible.

   No reason to include in test program.

8. A common fault in RHPP site audits.

   Caused by poor choice of sensor or poor installation of sensor including strap-on sensors.

   Some tests already carried out by EMC and Graham Energy.

   One comprehensive data set required for clearer analysis of error.

   This error type creates opportunity / higher risk of fraud/tampering.

   Testing to be carried out to include effect of heat transfer/conductive paste.

9. Could be due to

   a) Incorrect fluid parameters eg, temperature, glycol concentration
   b) Low sampling rates (for battery operated meters)
   c) Unsteady flow

   Whilst errors due to incorrect fluid parameters can easily be calculated, testing on the effect of glycol concentration is proposed as a check on the effect of this variation. The variation due to temperature is lower and it is not proposed to test for this.

   Tests have been carried out to identify the errors caused by low sampling rates. It is proposed to exclude battery powered meters from the majority of tests. However, if time and budget constraints permit, it is proposed to try the battery meters on the intermittent flow test rig to assess the cumulative error caused by battery power and intermittent flow concurrently.

Test on glycol to cover the range 10% to 30% since it covers the most most likely to be encountered and allows interpolation for intermediate concentrations without having to extrapolate.

10. Transient operating conditions, which are especially likely with heat pump systems, could result in large errors particularly since heat pumps often operate with small temperature differences between the water flow and return. Transient conditions are difficult to simulate in the laboratory in a repeatable manner and therefore there is little data on the effect on heat meter accuracy. The proposed test method therefore includes testing in a heat pump test rig to reduce avoid the limitations of laboratory test rig testing.

Additional notes / considerations

11 Heat meter accuracy over time

The test programme cannot directly address this question. However, the tests will determine the sensitivity of different types of heat meter to factors such as dirt and air that may have a long term impact on accuracy, and also how factors such as orientaion may affect this sensitivity. "

12 Recalibration intervals

The test programme will not directly address this but as explained in note 11 above the results of the proposed testing will inform this and allow value based recommendations to be made."

13 Reliability of different heat meter types

The test programme will not directly address this but similar to 11 and 12 above it will inform this and allow value based recommendations to be made.

This question will also be informed by the testing of old heat meters obtained from existing installations."

14 Requirements for system cleaning / flushing to maintain accuracy

The test programme will not directly address this but similar to 13 above inspection and testing of old heat meters (including heat meters that have been operated in BRE's test houses for more than 20 years without cleaning or flushing) will allow the effect of lack of cleaning / flushing to be assessed. "

Appendix E Maximum Permitted Errors

The maximum permitted errors for heat meters as determined by the MID Directive are shown below.

DN20 Maximum Permitted Flow Sensor Error

q l/s	0.015	0.020	0.025	0.050	0.100	0.200	0.300	0.500	0.700	0.900
qp m3/h	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
qp/q	46.30	34.72	27.78	13.89	6.94	3.47	2.31	1.39	0.99	0.77
Class 2 %	2.9	2.7	2.6	2.3	2.1	2.1	2.0	2.0	2.0	2.0
Class 3 %	5.0	4.7	4.4	3.7	3.3	3.2	3.1	3.1	3.0	3.0
Class 2 %	-2.9	-2.7	-2.6	-2.3	-2.1	-2.1	-2.0	-2.0	-2.0	-2.0
Class 3 %	-5.0	-4.7	-4.4	-3.7	-3.3	-3.2	-3.1	-3.1	-3.0	-3.0

q = water flow rate

qp = the highest value of q that is permitted permanently for the heat meter to function correctly

Maximum permitted Temperature Sensor Pair Error

dØ	3	4	5	6
dØ min	3	3	3	3
Error %	3.5	2.75	2.3	2

Maximum Permitted Calculator Error

dØ	3	4	5	6
dØ min	3	3	3	3
Error %	1.5	1.25	1.1	1

Total permitted heat meter error is sum of temperature sensor error + flow sensor error + calculator error

DN20 (qp = 2.5 m^3/h) Maximum permitted total error at 3K (%)

q l/s	0.015	0.02	0.025	0.05	0.1	0.2	0.3	0.5	0.7	0.9
Class 2 %	7.9	7.7	7.6	7.3	7.1	7.1	7.0	7.0	7.0	7.0
Class 3%	10.0	9.7	9.4	8.7	8.3	8.2	8.1	8.1	8.0	8.0
Class 2 %	-7.9	-7.7	-7.6	-7.3	-7.1	-7.1	-7.0	-7.0	-7.0	-7.0
Class 3%	-10.0	-9.7	-9.4	-8.7	-8.3	-8.2	-8.1	-8.1	-8.0	-8.0

DN20 (qp = 2.5 m^3/h) Maximum permitted total error at 5K (%)

q l/s	0.015	0.020	0.025	0.050	0.100	0.200	0.300	0.500	0.700	0.900
Class 2 %	6.3	6.1	6.0	5.7	5.5	5.5	5.4	5.4	5.4	5.4
Class 3%	8.4	8.1	7.8	7.1	6.7	6.6	6.5	6.5	6.4	6.4
Class 2 %	-6.3	-6.1	-6.0	-5.7	-5.5	-5.5	-5.4	-5.4	-5.4	-5.4
Class 3%	-8.4	-8.1	-7.8	-7.1	-6.7	-6.6	-6.5	-6.5	-6.4	-6.4

DN25 Permitted Flow Sensor Error

q l/s	0.015	0.020	0.025	0.050	0.100	0.200	0.500	1.000	32.000	3.000
qp m3/h	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
qp/q	64.81	48.61	38.89	19.44	9.72	4.86	1.94	0.97	0.03	0.32
Class 2 %	3.3	3.0	2.8	2.4	2.2	2.1	2.0	2.0	2.0	2.0
Class 3 %	5.0	5.0	4.9	4.0	3.5	3.2	3.1	3.0	3.0	3.0
Class 2 %	-3.3	-3.0	-2.8	-2.4	-2.2	-2.1	-2.0	-2.0	-2.0	-2.0
Class 3 %	-5.0	-5.0	-4.9	-4.0	-3.5	-3.2	-3.1	-3.0	-3.0	-3.0

q = water flow rate

qp = the highest value of q that is permitted permanently for the heat meter to function correctly

Maximum permitted Temperature Sensor Pair Error

dØ	3	4	5	6	10	30
dØ min	3	3	3	3	3	3
Error %	3.5	2.75	2.3	2	1.4	0.8

Maximum Permitted Calculator Error

dØ	3	4	5	6	10	30
dØ min	3	3	3	3	3	3
Error %	1.5	1.25	1.1	1	0.8	0.6

Total permitted heat meter error is sum of temperature sensor error + flow sensor error + calculator error

DN25 (qp = 3.5 m^3/h) Maximum permitted total error at 3K (%)

q l/s	0.015	0.02	0.025	0.05	0.1	0.2	0.5	1	32	3
Class 2 %	8.3	8.0	7.8	7.4	7.2	7.1	7.0	7.0	7.0	7.0
Class 3%	10.0	10.0	9.9	9.0	8.5	8.2	8.1	8.0	8.0	8.0
Class 2 %	-8.3	-8.0	-7.8	-7.4	-7.2	-7.1	-7.0	-7.0	-7.0	-7.0
Class 3%	-10.0	-10.0	-9.9	-9.0	-8.5	-8.2	-8.1	-8.0	-8.0	-8.0

DN25 (qp = 3.5 m^3/h) Maximum permitted total error at 5K (%)

q l/s	0.015	0.020	0.025	0.050	0.100	0.200	0.500	1.000	32.000	3.000
Class 2 %	6.7	6.4	6.2	5.8	5.6	5.5	5.4	5.4	5.4	5.4
Class 3%	8.4	8.4	8.3	7.4	6.9	6.6	6.5	6.4	6.4	6.4
Class 2 %	-6.7	-6.4	-6.2	-5.8	-5.6	-5.5	-5.4	-5.4	-5.4	-5.4
Class 3%	-8.4	-8.4	-8.3	-7.4	-6.9	-6.6	-6.5	-6.4	-6.4	-6.4

DN25 (qp = 3.5 m^3/h) Maximum permitted total error at 10K (%)

q l/s	0.015	0.02	0.025	0.05	0.1	0.2	0.5	1	32	3
Class 2 %	5.5	5.2	5.0	4.6	4.4	4.3	4.2	4.2	4.2	4.2
Class 3%	7.2	7.2	7.1	6.2	5.7	5.4	5.3	5.2	5.2	5.2
Class 2 %	-5.5	-5.2	-5.0	-4.6	-4.4	-4.3	-4.2	-4.2	-4.2	-4.2
Class 3%	-7.2	-7.2	-7.1	-6.2	-5.7	-5.4	-5.3	-5.2	-5.2	-5.2

DN25 (qp = 3.5 m^3/h) Maximum permitted total error at 30K (%)

q l/s	0.015	0.02	0.025	0.05	0.1	0.2	0.5	1	32	3
Class 2 %	4.7	4.4	4.2	3.8	3.6	3.5	3.4	3.4	3.4	3.4
Class 3%	6.4	6.4	6.3	5.4	4.9	4.6	4.5	4.4	4.4	4.4
Class 2 %	-4.7	-4.4	-4.2	-3.8	-3.6	-3.5	-3.4	-3.4	-3.4	-3.4
Class 3%	-6.4	-6.4	-6.3	-5.4	-4.9	-4.6	-4.5	-4.4	-4.4	-4.4

DN40 Maximum permitted Flow Sensor Error

q l/s	0.05	0.20	0.30	0.50	1.00	2.00	3.00	4.00	5.00	8.00
qp m3/h	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
qp/q	55.6	13.9	9.3	5.6	2.8	1.4	0.9	0.7	0.6	0.3
Class 2 %	3.1	2.3	2.2	2.1	2.1	2.0	2.0	2.0	2.0	2.0
Class 3 %	5.0	3.7	3.5	3.3	3.1	3.1	3.0	3.0	3.0	3.0
Class 2 %	-3.1	-2.3	-2.2	-2.1	-2.1	-2.0	-2.0	-2.0	-2.0	-2.0
Class 3 %	-5.0	-3.7	-3.5	-3.3	-3.1	-3.1	-3.0	-3.0	-3.0	-3.0

q = water flow rate

qp = the highest value of q that is permitted permanently for the heat meter to function correctly

Maximum permitted Temperature Sensor Pair Error

dT	3	4	5	6
dT min	3	3	3	3
Error %	3.5	2.75	2.3	2

Maximum Permitted Calculator Error

dT	3	4	5	6
dT min	3	3	3	3
Error %	1.5	1.25	1.1	1

Total permitted heat meter error is sum of temperature sensor error + flow sensor error + calculator error

DN40 (qp = 10.0 m^3/h) Maximum permitted total error at 3K (%)

q l/s	0.05	0.20	0.30	0.50	1.00	2.00	3.00	4.00	5.00	8.00
Class 2 %	8.1	7.3	7.2	7.1	7.1	7.0	7.0	7.0	7.0	7.0
Class 3%	10.0	8.7	8.5	8.3	8.1	8.1	8.0	8.0	8.0	8.0
Class 2 %	-8.1	-7.3	-7.2	-7.1	-7.1	-7.0	-7.0	-7.0	-7.0	-7.0
Class 3%	-10.0	-8.7	-8.5	-8.3	-8.1	-8.1	-8.0	-8.0	-8.0	-8.0

DN40 (qp = 10.0 m^3/h) Maximum permitted total error at 5K (%)

q l/s	0.05	0.20	0.30	0.50	1.00	2.00	3.00	4.00	5.00	8.00
Class 2 %	6.5	5.7	5.6	5.5	5.5	5.4	5.4	5.4	5.4	5.4
Class 3%	8.4	7.1	6.9	6.7	6.5	6.5	6.4	6.4	6.4	6.4
Class 2 %	-6.5	-5.7	-5.6	-5.5	-5.5	-5.4	-5.4	-5.4	-5.4	-5.4
Class 3%	-8.4	-7.1	-6.9	-6.7	-6.5	-6.5	-6.4	-6.4	-6.4	-6.4

Appendix F Distributions in Monte Carlo Analysis

The use of Monte Carlo analysis allows any distribution to be assumed for the individual errors which make up the overall uncertainty in the measured result. This Appendix describes four of the most commonly used options:

- Normal distribution
- Truncated normal distribution
- Uniform distribution
- Discrete distribution

Throughout the discussion the simple example from the main text is used, in which temperature difference is measured to within ±1% and flow to within ±2%. These quantities are then multiplied together to derive heat. These errors are small, and if they are further assumed to be normally distributed the error bar of the associated product can be simply calculated analytically as $\pm\sqrt{(12 + 22)} = \pm 2.2\%$.Monte Carlo analysis will be used to explore the impact of a range of different distributions on this estimated uncertainty level.

Normal Distribution

The distribution most commonly used to characterise measurement errors is the normal distribution. There are two main reasons for its widespread use:

- The central limit theorem states that if a sufficiently large number of identically distributed sources of error are added together, the distribution of the result will tend towards normal. This is often used as a rather tenuous justification for assuming that errors will be normal in their distribution, on the basis that they are themselves the result of the effect of many smaller errors; and
- The normal distribution is particularly amenable to an analytical treatment, and assuming that all errors are distributed this way allows many calculations to be carried out without the need of numerical methods.

The histogram below shows the normal distribution corresponding to a 95% confidence interval of ±1%.

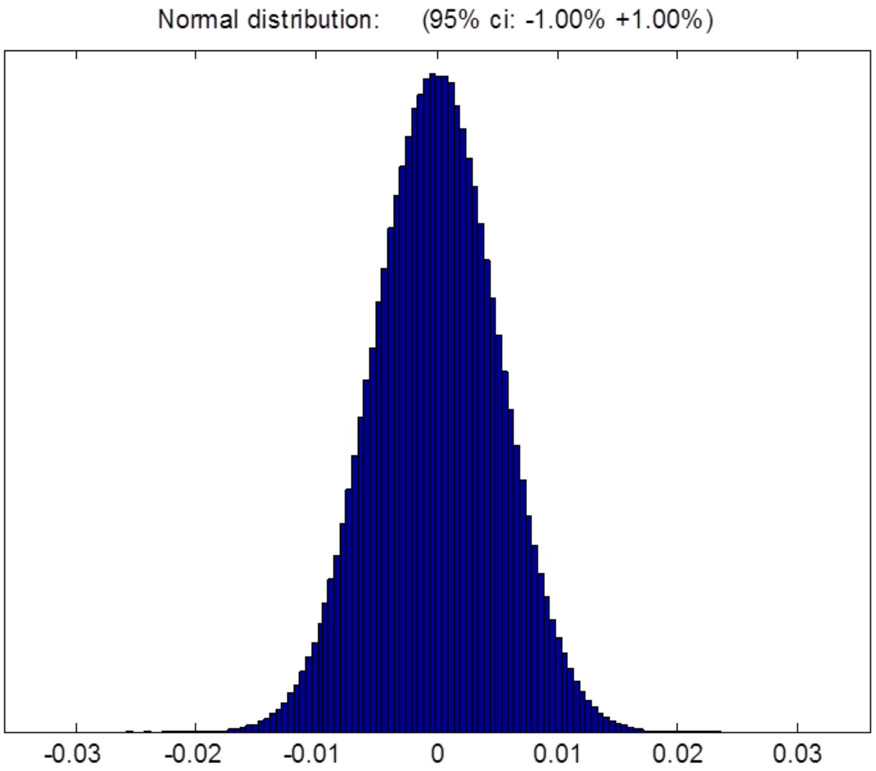


Figure 58: Normal distribution

As expected, carrying out a Monte Carlo analysis using this distribution gives a result which agrees with the analytical value of ±2.2%.

Truncated normal distribution

The normal distribution has tails which extend out to infinity in both directions. This makes it a poor distribution to use in many cases, since an equipment manufacturer If the quoted measurement uncertainty is initially regarded as a 95% confidence interval and the appropriate normal distribution then truncated the result is as shown below.

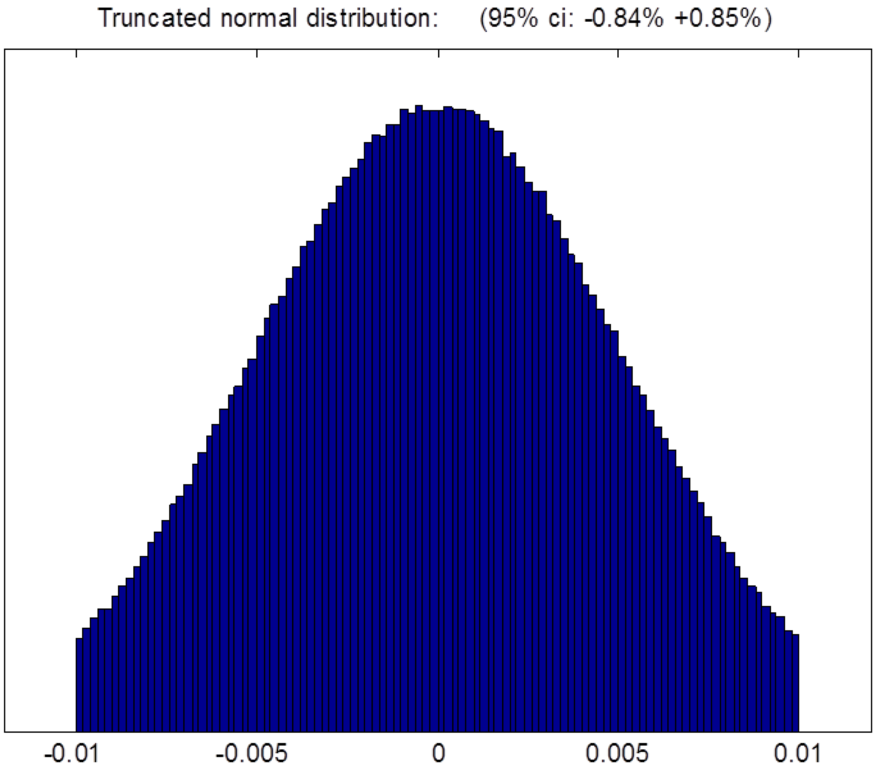


Figure 59: Truncated normal distribution

This approach largely retains the sometimes desirable form of the normal distribution, but solves the problem of errors falling outside of the quoted limits. Because it removes readings from the limits of the error it would be expected to reduce the estimate of total error. This is confirmed by the Monte Carlo analysis which, combining the two quantities with uncertainties of ±1%.and ±2% gives an overall error of ±1.9%.

Uniform distribution

The uniform distribution spreads the probability of an error occurring evenly across the width of the error band. There is thus no possibility of a sampled error falling outside of the band: a desirable property. The figure below show a uniform distribution for an error band of of ±1%.

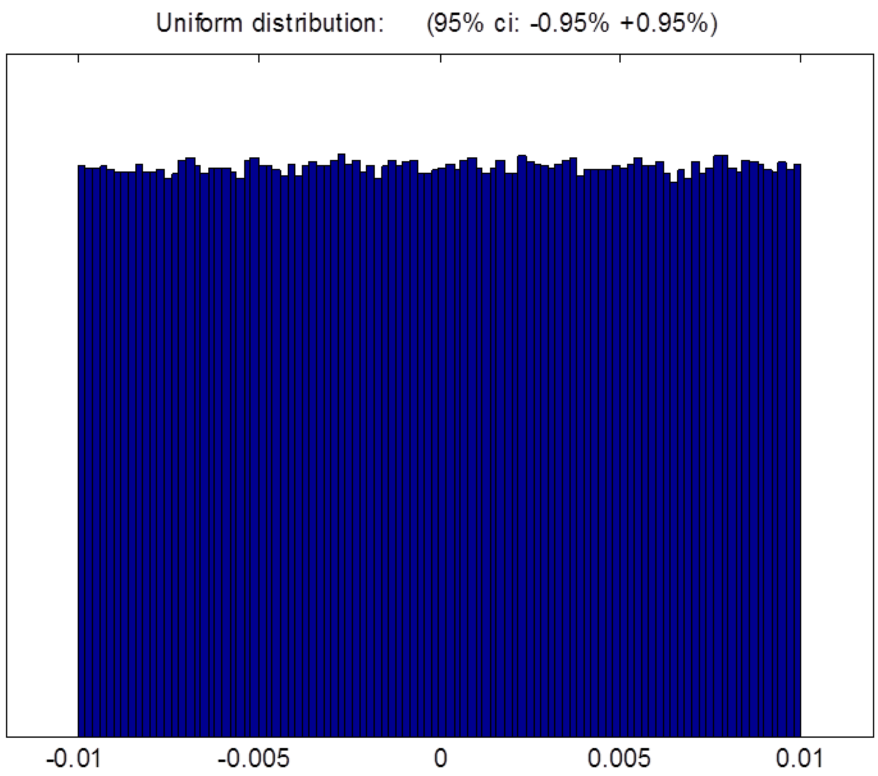


Figure 60: Uniform distribution

Because no points fall outside the quoted error band the 95% confidence interval is smaller by a factor of 0.95 . Compared to the normal distribution, this distribution forces more of the probability out towards the ends of the error range. It might be expected that this results in a larger estimate of overall uncertainty. This is the case: repeating the above simulation assuming that both variables are uniformly distributed over the intervals of ±1%. and ±2% increases the 95% confidence interval of the product of the two quantities slightly, to ±2.4%..

A uniform distribution of errors would be expected in cases where an instrument is adjusted until its reading falls within the required error band, and then no further effort was made to improve it. It can also result when sensors of a high accuracy grade are selected from a population of lower grade sensors (this practice is common in the electronics industry). In this case the sensors are effectively being selected from the area in the middle of the overall distribution, and their distribution is likely to be approximately uniform.

Discrete distribution

The distributions described have so far all related to continuous errors, which may take any value within their specified range. In some cases errors are restricted to a limited number of values. In general this can be several values – for example there might be a range of errors caused by a number of different types of up-stream obstruction.

The graph below shows an example of a particularly important discrete distribution, in which a ±1% error takes either its maximum positive or negative values which equal probabilities.

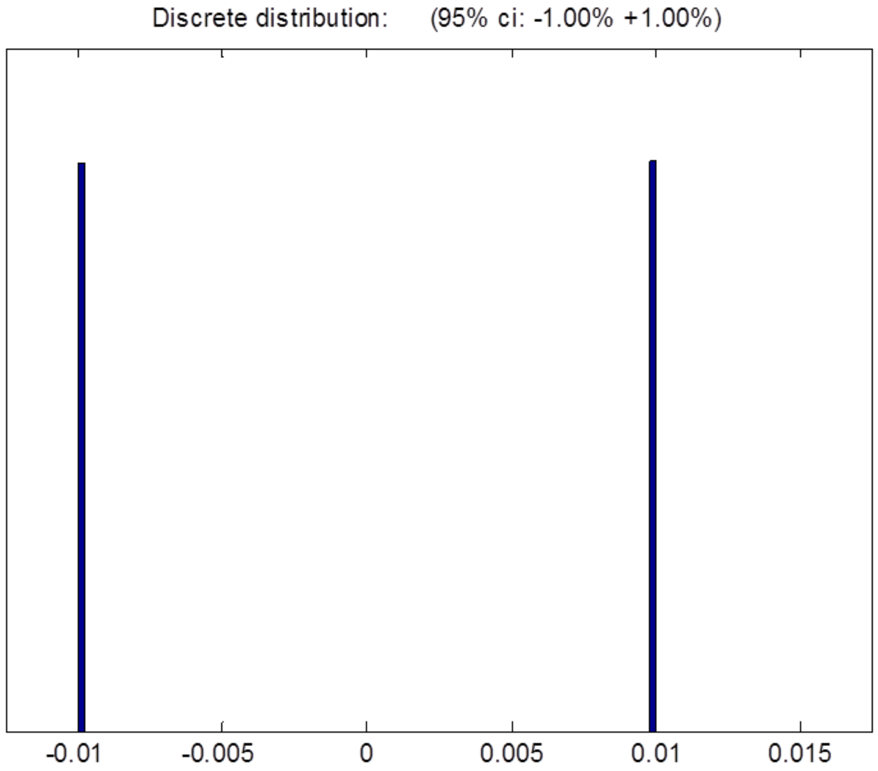


Figure 61: Discrete distribution

If both of the distributions in the simple example considered throughout this Appendix are assumed to be uniform with 50% of the probability placed at each extreme of the error interval then a Monte Carlo simulation estimates the resulting 95% confidence interval as ± 3.0%. This is the same as the result obtained by simply adding the absolute values of the errors. By always forcing the error in each value to one of its extremes this distribution gives the most pessimistic estimate of the overall error. It is what would be referred to in game theory as the ‘least favourable prior distribution’.

Conclusions

The table below summarises the results of these discussions.

Distribution	Error band
Normal	± 2.2%
Truncated normal	± 1.9%
Uniform	± 2.4%
Discrete	± 3.0%

Table 33: Error bands

It is clear that the choice of distribution can have a significant impact on the calculation of overall uncertainty, and that it should be given careful consideration alongside the actual magnitude of each error.

Appendix H All Monte Carlo inputs and results

This Appendix contains all of the input data used for the Monte Carlo runs. It also contains the results obtained from each meter type for both the RHI and RHPP populations combined and for the RHI sample alone. Finally, it presents an average result across all the meters, with the individual results weighted using the popularity of the meter within the RHI.

The table below gives the frequency of occurrence of each source of uncertainty using the two calculation methods.

Source of error	Probability of occurrence (all audit data)	Probability of occurrence (RHI audits only)
Basic instrument accuracy		
Class 2 flowmeter accuracy	100%	100%
Temperature difference accuracy	100%	100%
Calculator accuracy	100%	100%
Flow measurement errors		
Incorrect flowmeter orientation	9.5%	13.2%
Upstream flow perturbation	3.3%	2.1%
Gas entrainment	5.0% (Estimated)	5.0% (Estimated)
Dirt in system fluid	To be estimated when data is available	
Proximity to pumps	0.2%	0.2%

Mounting in flow rather than return	4.0%	4.0%
Temperature measurement errors		
Mounting sensors by strapping to the outside of the pipe	2.8%	2.0%
Missing insulation	1.6%	0.7%
Proximity of other heat sources to sensors	100%	100%
Heat calculation errors		
Use of system working fluids other than calibrated value (heat calculation)	25% (Estimated)	25% (Estimated)
Use of system working fluids other than calibrated value (flow calibration)	25% (Estimated)	25% (Estimated)

Table 34: Frequency of occurrence of each source of uncertainty

The next four tables give the impact of each source of uncertainty. Note for the discrete distributions assume that equal probability is assigned to each point so, for example in the case of mounting sensors by strapping it is assumed that at 50% of the affected sites this results in a 0.4% error

Input details for meter Ultrasonic A	
Source of error	**Error distribution**
Class 2 flowmeter accuracy	Truncated normal ±2.0%
Temperature difference accuracy	Truncated normal ±1.4%
Calculator accuracy	Truncated normal ±0.8%
Incorrect flowmeter orientation	Discrete -4.2%
Upstream flow perturbation	Discrete -1.4%

Gas entrainment	n/a
Dirt in system fluid	To be added when available
Proximity to pumps	Discrete -0.2%
Mounting in flow rather than return	Uniform 0.3%, 2.0%
Mounting sensors by strapping to the outside of the pipe	Discrete 0.4%, 5.9%
Missing insulation	Discrete -0.2%, 0.8%
Proximity of other heat sources to sensors	Uniform -0.9%, 0
Use of system working fluids other than calibrated value (heat calculation)	Normal ±1.5%
Use of system working fluids other than calibrated value (flow calibration)	Normal 0.4%, 0.8%

Table 35: Input details for Ultrasonic A

The class errors (flow and temperature difference measurement and calculator accuracy) are the same for each meter, and these have therefore been omitted from the remaining tables.

Input details for meter Ultrasonic B	
Source of error	**Error distribution**
Incorrect flowmeter orientation	Discrete 5.0%
Upstream flow perturbation	Discrete -0.8%
Gas entrainment	n/a
Dirt in system fluid	To be added when available

Proximity to pumps	Discrete 0.4%
Mounting in flow rather than return	Uniform 0.3%, 2.0%
Mounting sensors by strapping to the outside of the pipe	Discrete 2.4%, 4.2%
Missing insulation	Discrete 5%, -2.5%
Proximity of other heat sources to sensors	Uniform -0.9%, 0
Use of system working fluids other than calibrated value (heat calculation)	Normal ±1.5%
Use of system working fluids other than calibrated value (flow calibration)	Normal -0.8%, -0.6%

Table 36: Input details for Ultrasonic B

Input details for meter Vortex	
Source of error	**Error distribution**
Incorrect flowmeter orientation	Discrete -4.0%
Upstream flow perturbation	Discrete -0.8%
Gas entrainment	Discrete 1.0%
Dirt in system fluid	To be added when available
Proximity to pumps	Discrete -1.9%
Mounting in flow rather than return	Uniform 0.3%, 2.0%
Mounting sensors by strapping to the outside of the pipe	Discrete -1.8%, 6.2%

Missing insulation	Discrete -0.5%, 0.4%
Proximity of other heat sources to sensors	Uniform -0.9%, 0
Use of system working fluids other than calibrated value (heat calculation)	Normal ±1.5%
Use of system working fluids other than calibrated value (flow calibration)	Normal -1.1%, 2.5%

Table 37: Input details for Vortex

Input details for meter Rotary	
Source of error	**Error distribution**
Incorrect flowmeter orientation	Discrete -0.1%
Upstream flow perturbation	Discrete 0.8%
Gas entrainment	Discrete 0.3%
Dirt in system fluid	To be added when available
Proximity to pumps	Discrete -1.4%
Mounting in flow rather than return	Uniform 0.3%, 2.0%
Mounting sensors by strapping to the outside of the pipe	Discrete 8.9%,36.2%
Missing insulation	Discrete -0.3%, 0.9%
Proximity of other heat sources to sensors	Uniform -0.9%, 0
Use of system working fluids other than calibrated value (heat calculation)	Normal ±1.5%

Use of system working fluids other than calibrated value (flow calibration)	Normal -0.5%, 0.2%

Table 38: Input details for Rotary

The next four figures show the results of the Monte Carlo runs for each meter, assuming that the probability of each type of error occurring is as calculated from the whole sample of RHI and RHPP audits.

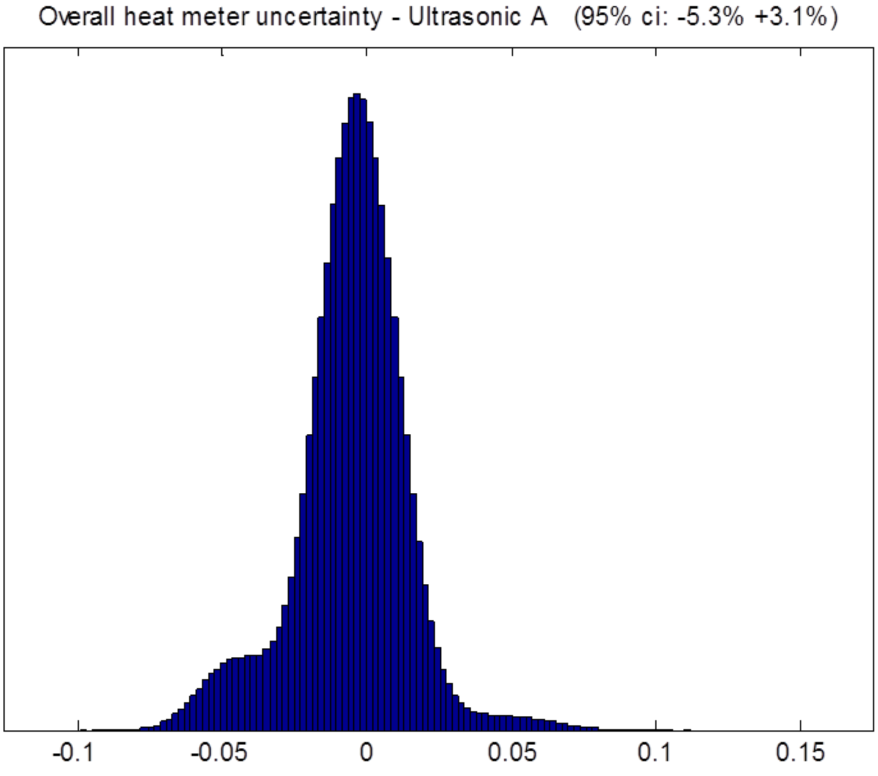


Figure 62: Results of Monte Carlo run for Ultrasonic A (whole sample of RHA and RHPP audits)

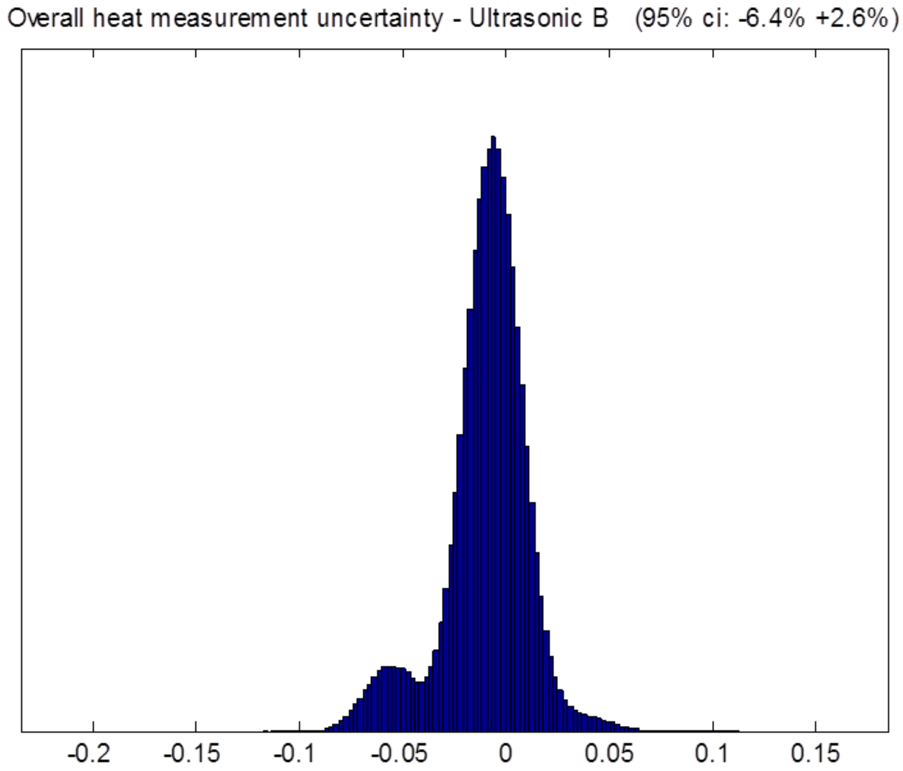


Figure 63: Results of Monte Carlo run for Ultrasonic B (whole sample of RHA and RHPP audits)

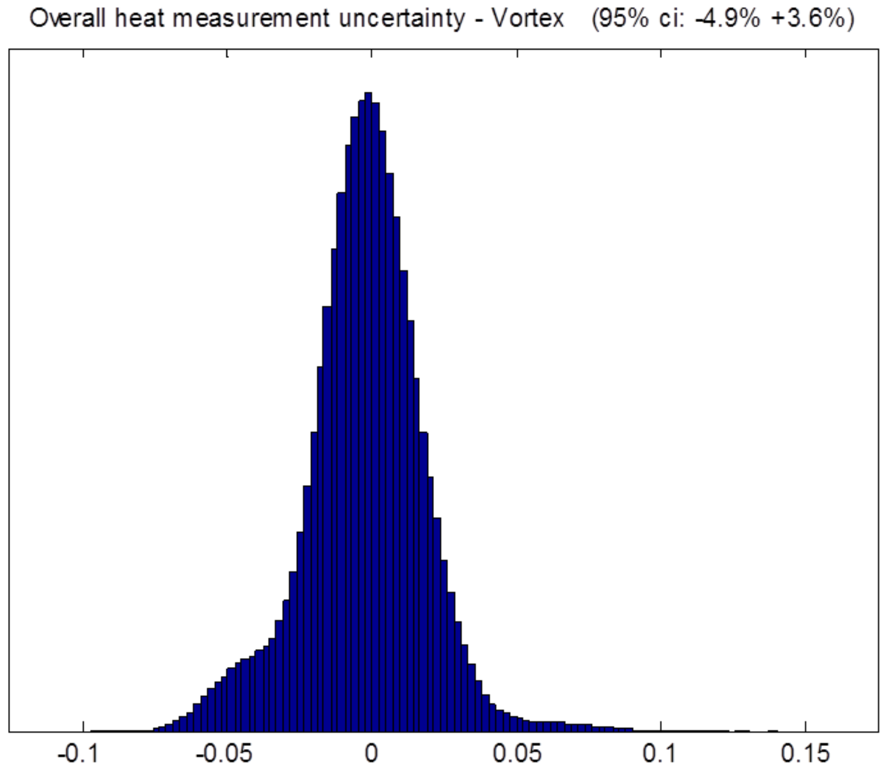


Figure 64: Results of Monte Carlo run for Vortex (whole sample of RHA and RHPP audits)

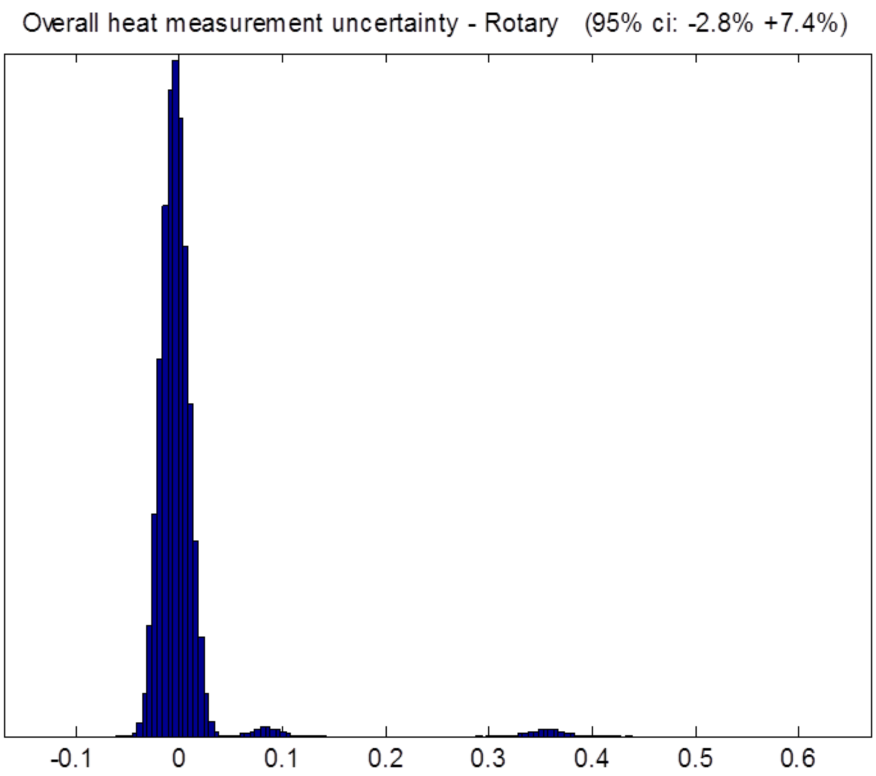


Figure 65: Results of Monte Carlo run for Rotary (whole sample of RHA and RHPP audits)

The next four figures give the corresponding results when the error probabilities are calculated from the RHI audit data alone.

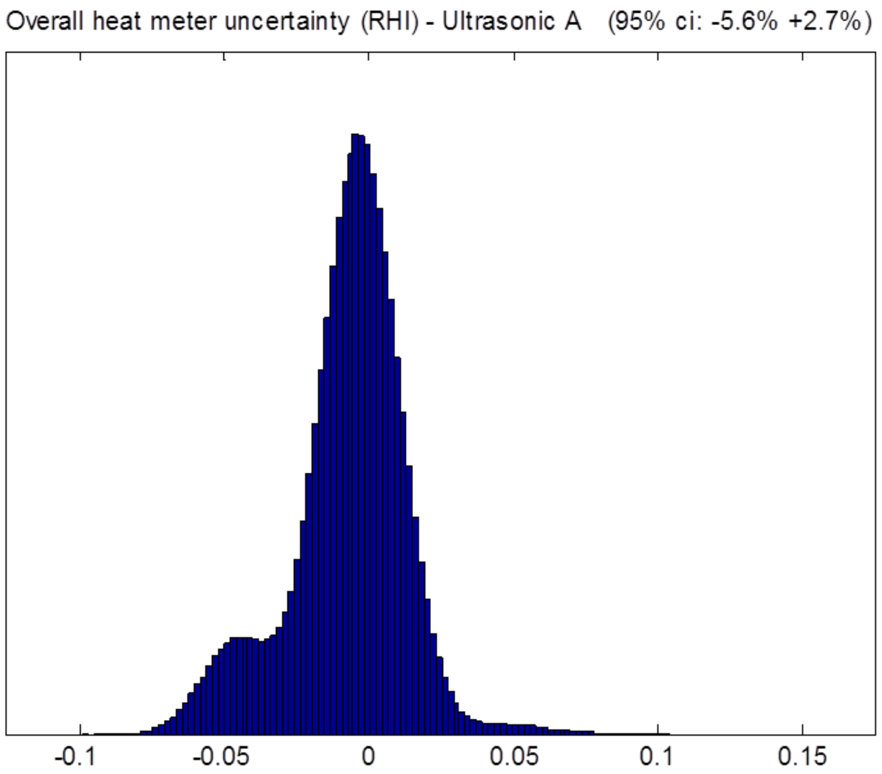


Figure 66: Results of Monte Carlo run for Ultrasonic A (sample of RHA audits only)

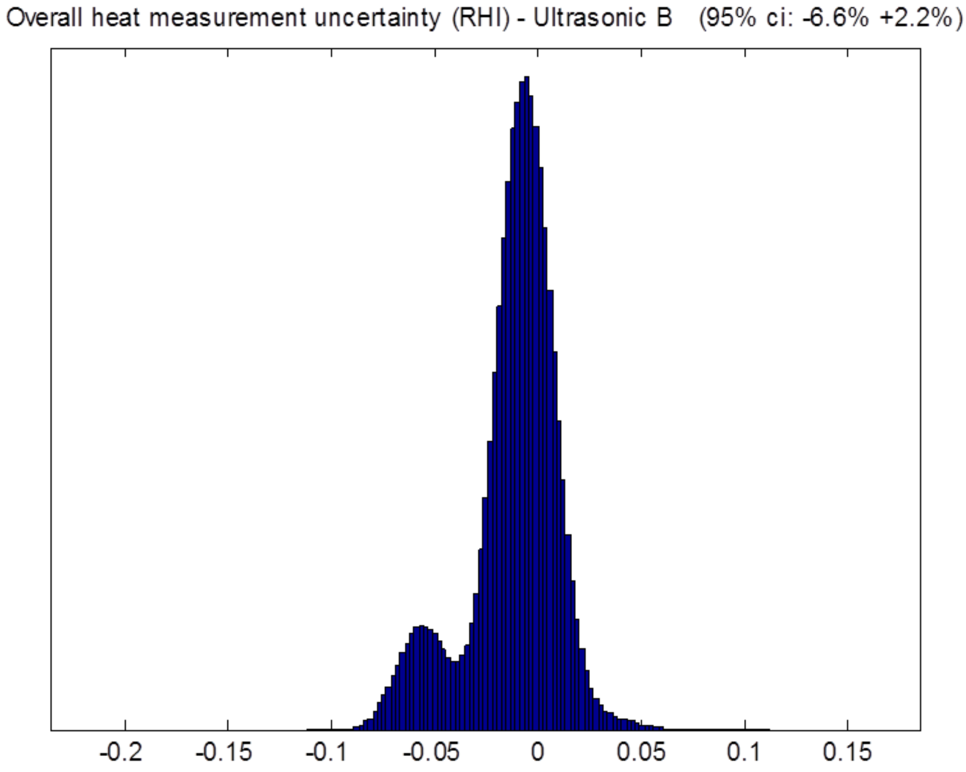


Figure 67: Results of Monte Carlo run for Ultrasonic B (sample of RHA audits only)

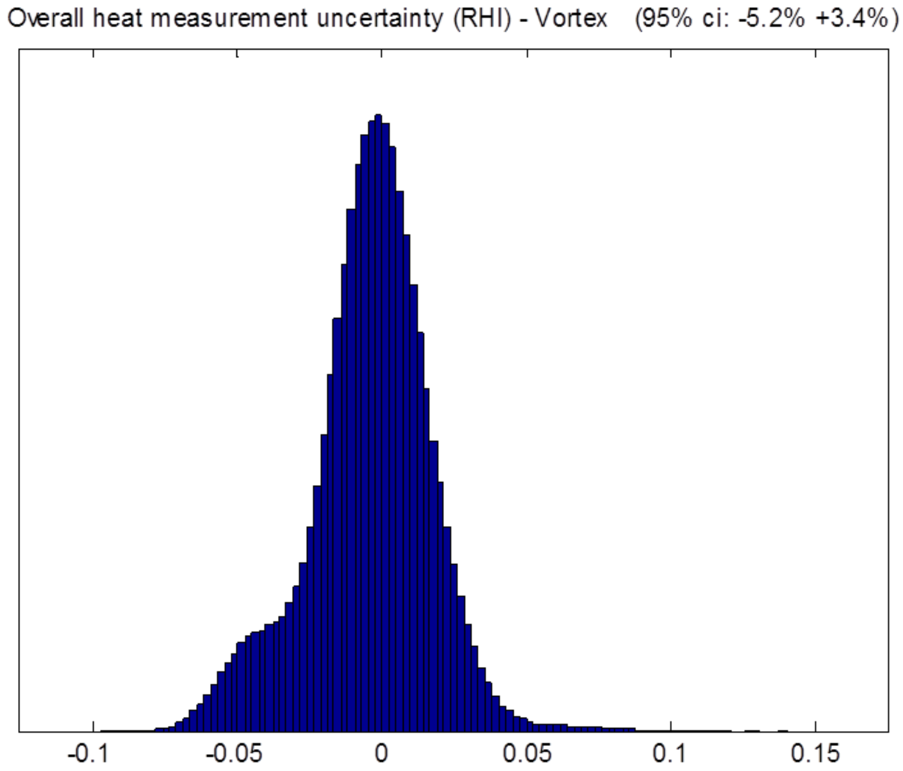


Figure 68: Results of Monte Carlo run for Vortex (sample of RHA audits only)

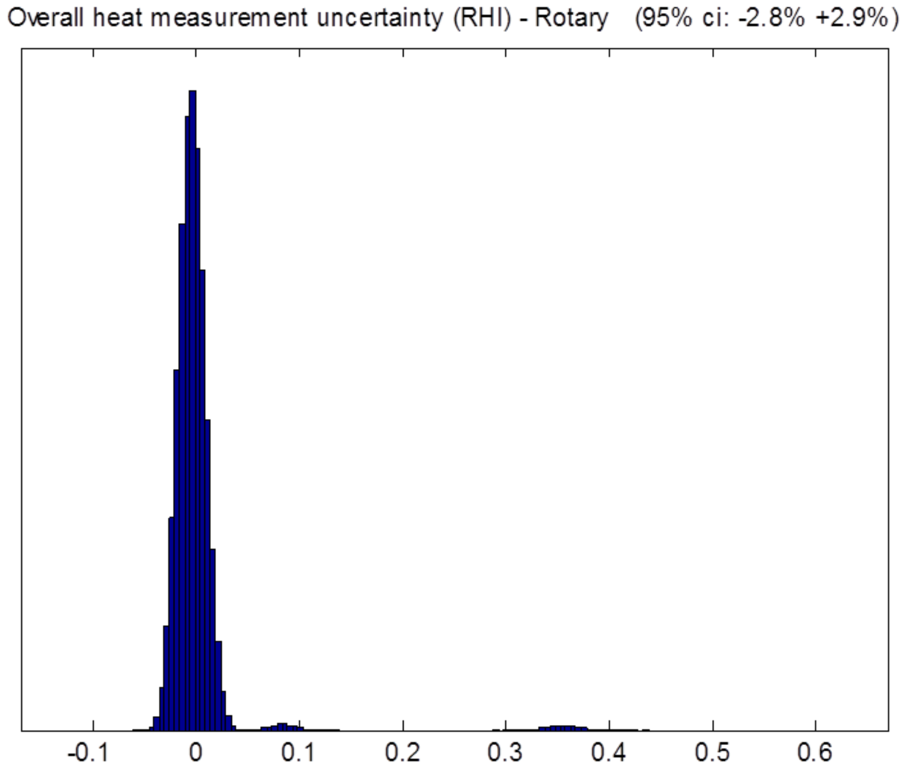


Figure 69: Results of Monte Carlo run for Rotary (sample of RHA audits only)

The final graph presented in the main text shows the result of combining these last four results using the appropriate weightings from the RHI.

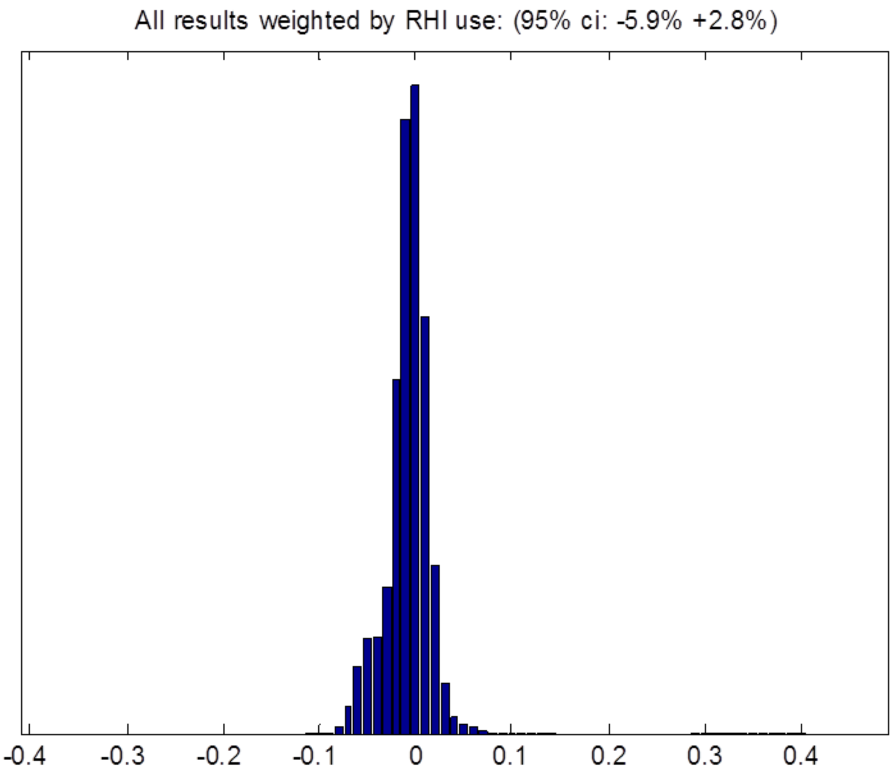


Figure 70: Combination of results for all meters (sample of RHI audits only)

Appendix G Effect of dirt

Tests were undertaken on four types of DN25 heat meters (one vortex, two ultrasonic, and one rotary) installed in a 1990s BRE test house with a contemporary heating system continually contaminated by dirt and air. The duration of these tests was from 22 June 2015 to 1 February 2016. At the end of the tests the heat meter flow meter units were removed and inspected internally.

The heating system comprised standard steel panel radiators which had been in use for over 20 years. An electric boiler was used in place of the original gas boiler so that the heat energy could be accurately measured using an electric energy meter. This meant that the evaluation of heat energy could be independent of the water flow rate in case the reference flow meter was also affected by dirt. The heat meters were installed in series with a laboratory reference electromagnetic flow meter.

The system had not been maintained over time and did contain any inhibitors, inline magnets or strainers. An open tank was introduced into the heating system at a high level and arranged so that the circulating flow cascaded into this tank upstream of where the heat meters were installed. This was designed so that dirty water could be re-introduced into the system after being removed directly from the radiators, allowed the water quality to be inspected visually and also allowing continuous aeration of the circulating water to speed up internal radiator corrosion. Figure 71 below shows an example of water quality.

Figure 71: Test house installation – example of heating system water quality

BRE experience is that radiators tend to act as effective dirt separators by separating and retaining dirt in the radiator. This effect was reduced by regularly removing contaminated water directly from two radiators in the heating system twice weekly on a rotation basis. This had the effect of ensuring that the system was constantly subject to circulating dirty water, a scenario that is worse than can be expected to be encountered in practice, when dirt tends to accumulate in the radiators.

The heat meter temperature sensors from all but one heat meter and the reference set of temperature sensors were installed in ‘Binder’ type test points so that the sensors were in direct contact with the water which eliminated any possible sensor mounting error. The metal sheath of the temperature sensors from the rotary heat meter were found to corrode causing premature failure of the sensors so replacement sensors were strapped to the outside of the pipes with thermal conductive paste and insulation. The manufacturer had supplied the sensors with sensor pockets and had these been used it is probable that premature failure of the sensors would have been avoided. The manufacturer’s technical literature provided no information on this aspect but in fairness the sensor diameter was not suitable for standard ‘Binders’ and their use in domestic heating systems is unusual. This led to an interruption in the collection of energy data from this meter although it did not affect the flow volume data. The sensors from all the other heat meters and the reference sensors were stainless steel sheathed which proved to be resistant to corrosion in this heating system. It is noted that water quality varies across the UK and heating systems can sometimes be affected by microbial infection (for example pseudomonas) that can cause rapid corrosion of standard metal pipework and fittings. This is the reason why additives containing corrosion inhibitors and biocides are often recommended, but not always used.

The heat energy into the heating system was evaluated using two methods; the metered electrical input to the electric flow boiler and evaluation of heat energy from the reference temperature sensors on the inlet and outlet of the flow boiler and reference electromagnetic flow meter. Readings were recorded at 5 minute intervals across the total test duration using an electronic data logger. The flow boiler was manually set for a fixed electrical power input depending on the prevailing weather and therefore the change in water inlet and outlet temperatures was very slow permitting a 5 minute data recording period. A comparison between the totalised electrical energy input and heat energy (calculated from temperature and flowrate) is shown in Figure 72. The total heat energy was 1.2% less than the total electrical energy. This is a very small difference and shows that the reference electromagnetic flow meter was not significantly affected by the dirt in the system.

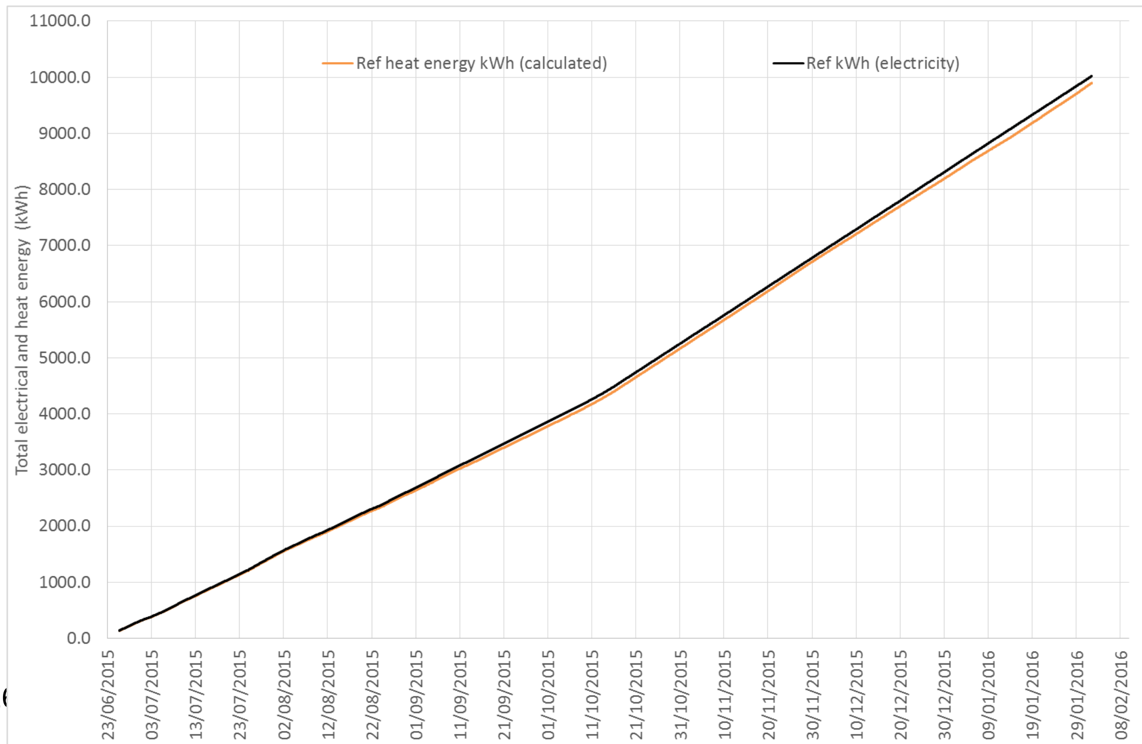


Figure 72 Comparison of total metered electrical energy and total heat energy

Heat energy and water flow volume recorded by the heat meters was measured by counting the heat meter pulse outputs using a pulse counting electronic data logger at 5 minute intervals. Back-up manual meter readings were also taken on a weekly basis. Figure 73 and Figure 74 show the total meter flow volume and total metered energy. Flow volume data for the rotary heat meter was monitored over the entire test period but temperature sensor faults resulted in an incomplete data set for energy data. The missing data was replaced by a combination of data interpolation and by superimposing the flow volume error. Since the main cause of energy measurement error was related to the flow measurement this approach was considered reasonable.

Figure 73 shows the totalised flow volume and Figure 74 the totalised energy over the entire test duration. The overall differences in volume and energy at the end of the test period are shown below in Table 1. The daily variation in volume and energy error has also been calculated from this data and is shown in Figure 75 and Figure 76 respectively.

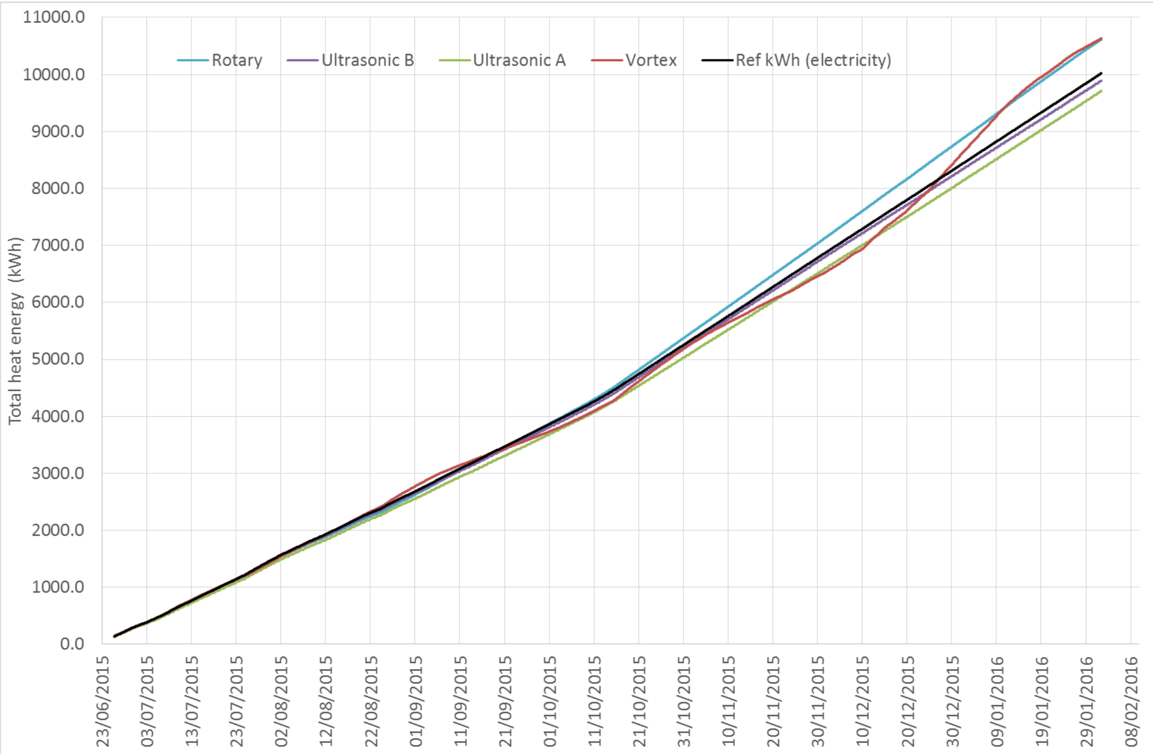


Figure 73 Total measured flow volume over whole test period

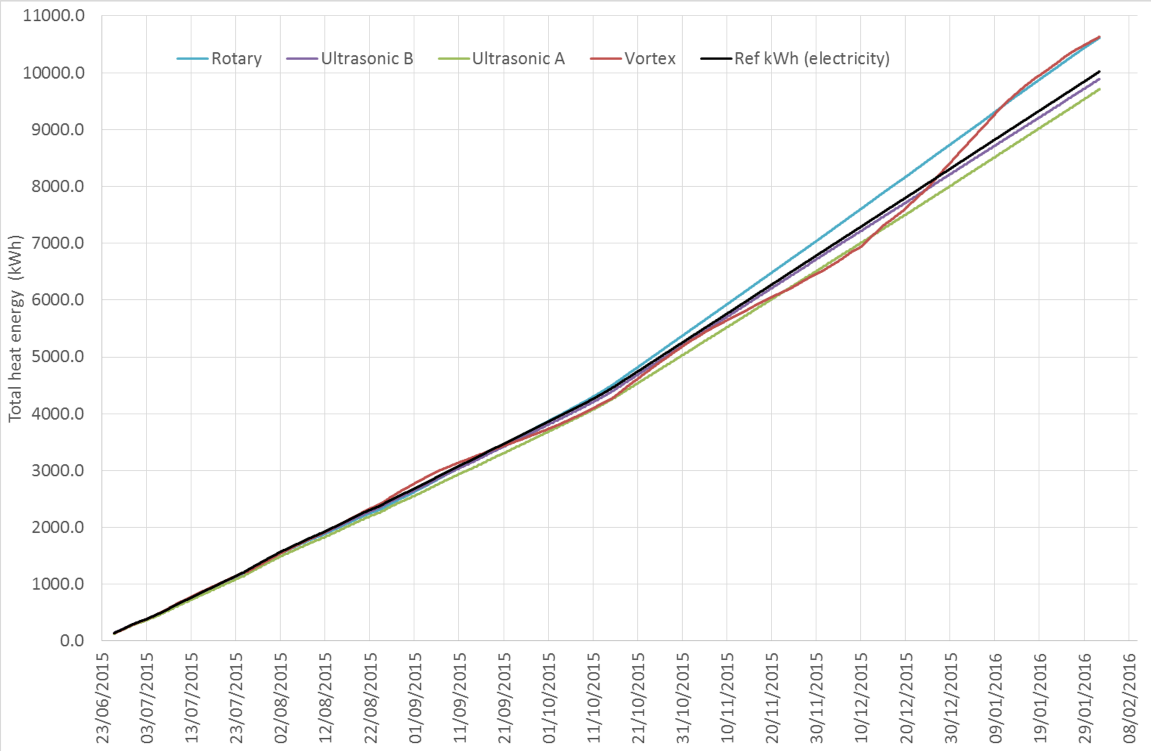


Figure 74 Total measured energy over whole test period

Ignoring the initial very high levels of error right at the beginning of the test, believed to be caused by initial high levels of circulating dirt and air, the two ultrasonic heat meters and electromagnetic flow meter errors stabilised which showed that these meters were little affected by the circulating dirt. The overall errors in metered energy for the ultrasonic heat meters were also less than 4% at the end of the test which is well within the permitted total heat meter error for a Class 2 heat meter at the average water flow rate (0.1 l/s) and dT (4.4K) during the test (see Appendix D). Despite a significantly greater variation in flow and energy accuracy the vortex and rotary heat meters were also within the maximum permitted overall error level for a Class 2 heat meter. It should be noted though that only the Ultrasonic A heat meter met the Class 2 and Class 3 flow sensor error criteria specified in the MID, but that all meters met the combined (flow sensor, temperature sensor pair and calculator) MID maximum permitted error.

The variation in daily flow and energy errors for the vortex and rotary heat meters suggests that these heat meters were much more affected by the circulating dirt than the ultrasonic heat meters and electromagnetic flow meter. It is also significant to note that over time the level of error for the vortex and rotary heat meters increased over time which suggests that they may be affected by a progressive build-up of dirt within the flowmeter units, although for the vortex unit this was not a constant progressive effect.

The test results show that the build-up of dirt has a significant effect on the vortex and rotary heat (flow) meters, whereas the effect was negligible on the ultrasonic and electromagnetic meters. Whilst the test was carried out over a six month period, the test methodology amplified the quantity of dirt and corrosion in the system. It could be expected that errors of the magnitude indicated in Table 39 and Table 40 could be encountered in dirty and poorly maintained systems after years (not months) of operation.

	Reference electromagnetic flow meter	Vortex	Ultrasonic A	Ultrasonic B	Rotary
Total recorded volume (m3)	2009	2217	2031	2081	2129
% error	-	10.3	1.1	3.6	6.0

Table 39 Total overall errors in volume at end of the test

	Electricity meter	Electromagnetic flow meter	Vortex	Ultrasonic A	Ultrasonic B	Rotary
Total recorded energy (kWh)	10024	9902	10635	9710	9890	10622
% error	-	-1.2	6.1	-3.1	-1.3	6.0

Table 40 Total overall errors in energy at end of the test

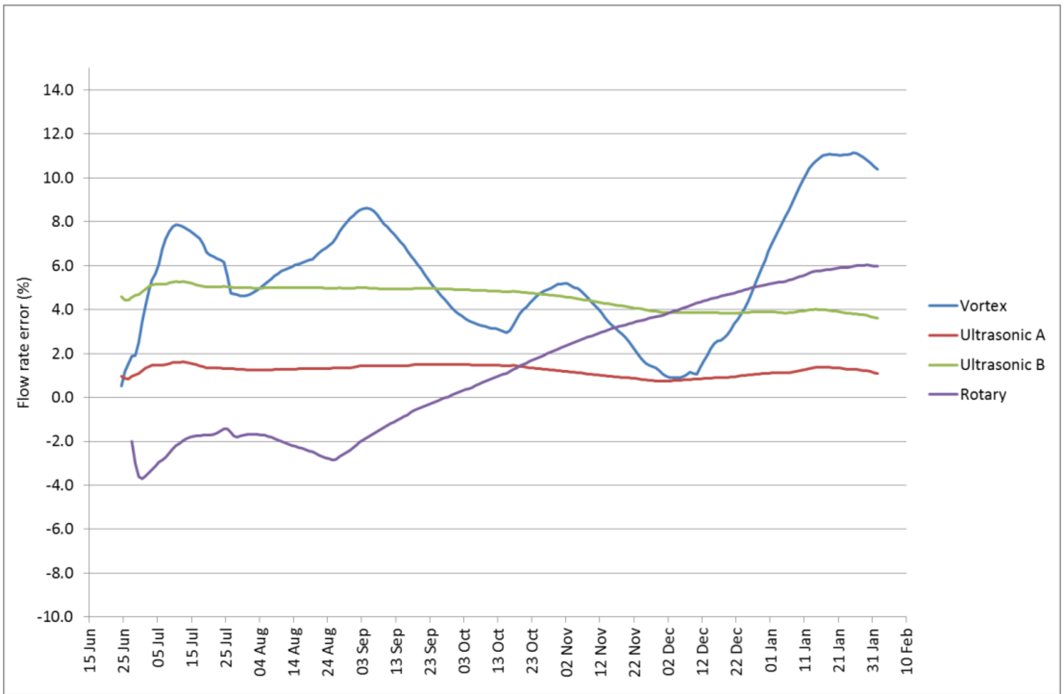


Figure 75 Variation (daily) in flow error for heat meters in dirty heating system

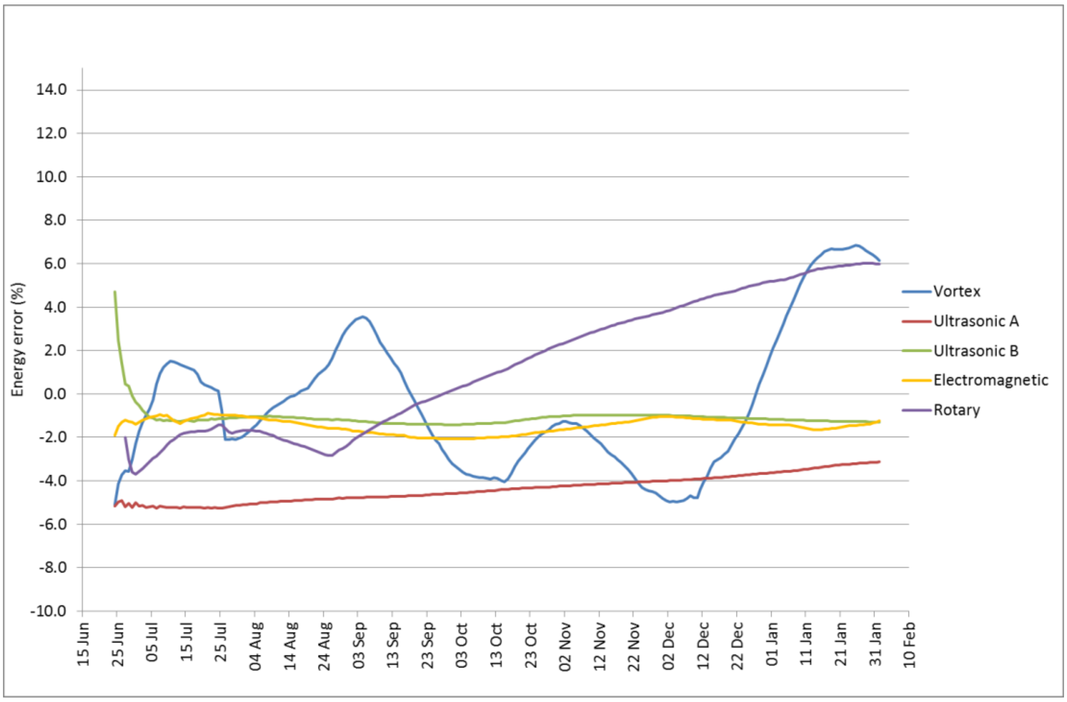
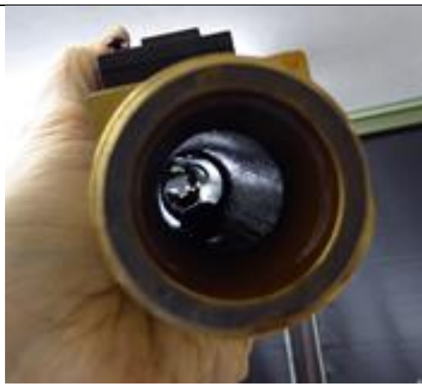


Figure 76 Variation (daily) in energy error for heat meters in dirty heating system

At the end of the test the heat meters were removed from the heating system and visually inspected. Photographs of the inlets and outlets are shown in Figure 77. These show very significant accumulations of sludge at the inlet to all of the flow meters. However, the middle sections and outlets of the ultrasonic and electromagnetic flowmeters were comparatively clear of major sludge and dirt deposits. In comparison the relatively intricate internal passages in the vortex flow meter and rotary flow meter had very large accumulations of sludge and this is no doubt the reason why these types of meter showed the largest reduction in measurement accuracy.   This is probably attributable to the method of flow measurement rather than specific to the brands of meters tested.

Electromagnetic flowmeter – inlet (left), outlet (right)

Vortex heat meter – inlet (left), internal (right)



Ultrasonic heat meter (A) - inlet (left), outlet (right)

Ultrasonic heat meter (B) - inlet (left), outlet (right)

Flowmeter from rotary heat meter - inlet (left), outlet (right)

Figure 77 Photographs of dirt inside heat meter flow sensors at end of test

Department of Energy & Climate Change
3 Whitehall Place
London SW1A 2AW
www.gov.uk/decc
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