MISREADING OF CONVENTIONAL DIAPHRAGM DOMESTIC GAS METER

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Background

In the Netherlands, the vast majority of all households are connected to the gas grid. Up to now, the consumption for domestic application is almost always measured using conventional diaphragm gas meters. In the Netherlands, we count some seven million end users with an individual gas meter. Reading and volume conversion errors can lead to erroneous billing. In 2007, Professor Dr A.F.P. van Putten of AnMar Research Laboratories reported on the implementation of the seven-degree method of gas measurement in the domestic end user market. More specifically, the assumption used on the gas temperature was discussed. Following this, the Executive Energy Regulation (DTe) (now Energiekamer of the Netherlands Competition Authority (NMa)) launched an investigation into the quality of this volume conversion method. The used diaphragm gas meters are neither temperature nor pressure corrected. To calculate the standard normal cubic meters, the so-called “seven-degree method” is used. This method assumes that the gas temperature entering the gas meter has an average temperature of seven degrees Celsius. Due to the method used, all end users’ gas volume readings are corrected in the same way. The question however is if this correction is fair for all end users.

Two following questions were raised:

- Is the “seven-degree method” appropriate?
- Is there a difference in the gas meter readings and is it fair for the end user?

A study to answer these questions was performed by KIWA Gas Technology (KGT), in close cooperation with and commissioned by NMa.

Methods

The study on this topic was split into two parts. The first part of the study dealing with the first question: “Is the method appropriate?” and the second part of the study dealing with the second question:”Is the method fair for all (domestic) end users?”
In order to give a correct answer to the second question, an extensive field study was needed to measure the relation between actual gas temperatures and reading of the diaphragm gas meter.

Part 1: Desk and laboratory study on the influence of the gas meter (mis)reading

To estimate the effects of the volume conversion in practice, a theoretical analysis of the heating rate of distributed natural gas was made. In this estimation the position and distance of the meter relative to the spot the service enters the building (different for high-rise buildings and one family houses), the influence of gas pressure and the influence of the air pressure were taken into account. The estimated heating of the gas at the outlet of the gas meter was verified using laboratory measurements. As misreading is also a part of total measurement error, this was also assessed by using the calibration information of these meters.

Part 2 Field study between December 2007 and March 2008 on the influence of the temperature on the meter reading

In order to verify the results of part 1, a field test was performed. In this study at 26 different households the misreading of the diaphragm gas meter was monitored. The 26 houses were chosen in such a way that a wide range of category of types of residential houses and design of the gas installation in practice were incorporated in the evaluation. The classification of each category was based on the building and gas installation characteristics, which can be expected to affect the gas temperature.
For logistical feasibility, locations in the region of Apeldoorn and in the service area of only one operator / metering company (Continuon / Nuon Monitoring) were selected. At each location, a measurement set installed was installed. These measurements sets were equipped for automatic gas and various temperatures (including the temperature of the gas in the gas meter) reading and were able to record over a period of more than three months. This was achieved, at each location, by adding a pulse generation to the gas meter. In addition, four temperature sensors were installed. The sensors were used to register the gas temperature, the temperature in the room of installation of the gas meter, temperature in the crawl space (if any) and the temperature of the service line at home entry (if possible). The pulse generator and temperature sensors were connected to a data acquisition system that gathered the data. The sample frequency of the data acquisition system was approximately once a minute. To reduce the amount of data to store in the memory module of the logging system, the average values with an interval of 15 minutes were saved. The memory was read and emptied manually.

Based both the results obtained from the field study and on the categorization of the total Dutch housing stock, an estimate of the total annual measurement error for all domestic consumers in the Netherlands was made.

Results

Part 1: Desk and laboratory study on the influence of the gas meter (mis)reading

Metrological errors

As described before the accuracy of conventional diaphragm gas meters is also a factor in the misreading of these types of gas meters. The quality (accuracy) of the diaphragm gas meters in service in the Netherlands is controlled randomly (the “Gas Meter Pool”). In this “Gas Meter Pool” a complete population of meters is approved or rejected, based on the monitoring results of a spot check of the gas meter. An evaluation of the audit results of this “Gas Meter Pool” over the last five years shows that the average variation between the conventional diaphragm gas meters is 0.92% (at the maximum volume flow rate) and -0.17% (at one fifth of the maximum volume flow rate). As volume flow rates differ for each customer and differ because of the type of meter, the size of the gas meter, type of gas equipment installed and the heating behaviour of the customer, an administrative correction for this (small) deviation, to adjust the misreading is impossible.

Theoretical errors of the volume conversion using the seven-degree method

In the Dutch “measuring conditions gas” (Meetvoorwaarden Gas-RNB) the conversion method for the conventional diaphragm gas meter is prescribed. This method is called the seven-degree method. This volume conversion method assumes that the weighed average gas temperature (in the gas meter) is seven degrees Celsius and the weighed average gas supply pressure equals 28 millibars, increased with 1013.25 millibars.

If this assumption, regarding the delivery pressure and delivery temperature of the gas in the gas meter is correct, according to Boyle Gay Lussac's law, one can calculate that the gas volume measured, under operating conditions (assuming an average of 28 millibars overpressure and 7°C), corresponds to the same volume, when expressed under normal conditions (0° C and 1.01325 bar). This equals the conditions mentioned in the Dutch Gas Act. In this way, the measured volume of gas is easily translated into normal conditions and thereby fulfils the requirements of Gas Act.

As already mentioned the correctness of the assumption that the weighed average temperature and pressure equals the values mentioned in the seven-degree method is questioned. Therefore a theoretical analysis of the temperature and pressure was performed. The main questions were:

- What is the heating rate of natural gas?
- To what extend is warming or cooling of the gas in the gas grid from the district station to the point where the gas enters the building of the customer a factor of importance?
- What is the effect of the heating of the gas when travelling from the place where the gas enters the building to the gas meter?
- How the gas meter is situated inside the customers’ premises?

- What is the effect of the gas pressure, as well as the prevailing pressure in the gas volume measurement?

Heating rate of natural gas.

The heating rate of the gas in the distribution pipe line in the ground depends on several factors, namely:

- The gas exchanges its heat with the tube wall. The heat transfer coefficient is a function of gas velocity and the pipe diameter (and slightly a function of wall roughness and bends present);
- The inner tube wall exchanges heat with the outer tube wall through the pipe material. This heat exchange is of course dependent on the pipe material. In the gas distribution in the Netherlands steel or PE are often used for pressers from 1 to 8 bars. PVC or PE is often used for low-pressure systems (100 or 30 millibars).
- The tube wall exchanges heat with the ground. This heat exchange is a function of soil type (sand, clay or peat) and to some extent, the water content of the soil.
- The soil exchanges heat with the atmosphere. The rate of heat exchange is a function of wind speed.

A combination of these factors will fix the actual heating rate of gas travelling trough a buried pipeline.

Warming or cooling of the gas in the gas grid from the district station to the point where the gas enters the building of the customer.

The gas in the low-pressure is supplied through district stations. In the district stations, the pressure is usually reduced from 8 bar to 100 millibars or 30 millibars. This pressure reduction is accompanied by a temperature drop of around 4 ^{o}C. The temperature drop through expansion of natural gas is called the Joule-Thompson effect.
The length over which the gas again assumes ground temperature is strongly dependent on the pipe diameter (D) and, to a lesser extent, depending on the gas velocity and soil composition. Kiwa records ground temperature on an hourly basis. These measurements are performed throughout the Netherlands. Based on these records, the average ground temperature on a yearly basis is around 10 ºC. The analysis reveals that, depending on the distance of the house relative to the district station, the gas temperature in the connecting pipe in front of the house is slightly lower than the ground temperature. This is due to the mentioned Joule-Thomson effect as a result of the reduction of the gas pressure (temperature = decrease) in the district station in combination of the heating of the gas by the surrounding soil. The magnitude of this effect is estimated at about 1 °C. This means that the average gas temperature in the service line directly in front of the building is higher than 7 °C. This gives rise to a positive error in gas measurement (disadvantage end consumer). The size of this effect in practice will be determined during the field test.

The effect of the heating of the gas when travelling from the place where the gas enters the building to the gas meter

For the "heat-up-length" of the gas in the pipeline between the entry point in the building and the gas meter an equal set of considerations as used in the previous section, apply. However, the

influence of the soil is absent. This is replaced by the effect of heat transfer directly to the surrounding air and radiative transfer to the surrounding walls.
Again, theoretically, a large variety of "heat-up" or "cooling-down-lengths" are possible. The value is mainly dependant on the speed of the gas.

The place of the gas meter inside the customers' premises

In the study, two typical situations that can affect the heating of the gas are described.

A favourable situation for the end consumer occurs when the gas meter is placed in a cupboard, located directly at a non-isolated exterior wall. The pipe length to the gas meter does not exceed 1 to 2 meters. We assume that the temperature meter for this situation is about 5 °C warmer than the ground temperature.
Assuming an average gas temperature of about 9 °C, the inlet temperature of the gas in the gas meter is about 10 °C to about 12 °C. For the seven-degree method, this results in a positive error in gas measurement (including volume conversion) of at least 1% (disadvantage for the end user).

The worst situation for end users occurs in the small scale-rise buildings where the meter is installed inside the apartment and where the heater is running more than average, as in old flats. Here, typical maximum temperatures around 24 °C occur. In these special situations, this results in a positive error in gas measurement (including volume conversion) of approximately 6% (disadvantage for the end user).

The effect of the gas pressure and atmospheric pressure

Effect of pressure
A distinction must be made between the 100 millibar gas grids (where a pressure regulators are installed) and 30 millibar gas grids (pressure control from the district station).
The weather-compensated pressure causes in both cases a systematic error, but in the second case (30 milibar gas grids), the pressure in the gas meter may drop, depending on demand, from 30 to 25 millibars millibars.
Dutch distribution gas grids are dimensioned to support the consumers' gas consumptions at -12 °C within the pre-described pressure drop. However, in the majority of all cases, the domestic gas consumption, due to partial loaded appliances, is less than half of maximum capacity. The magnitude of this effect on the pressure is 1 to 2 mbar or 0.1% to 0.2% at the expense of the end user who is located at the periphery of a delivery station. End users situated closer to a pressure regulator station experience this effect proportionally less.

Effect of atmospheric pressure
There may be a systematic effect in the gas measurement (using volume conversion) due to the pressure. The seven-degree method assumes that the average air pressure equals 1013.25 mbar. If the actual pressure in the longer term (eg annual) and weighted to gas consumption differs from the assumed average air pressure of 1013.25 mbar, there is a systematic error introduced into the gas measurement.

There is a link between low atmospheric pressure and high gas consumption (more wind, lower

temperatures). The error in gas measurement (after volume conversion) is proportional to the difference in air pressure relative to the applied pressure (1013.25 mbar). This error in gas measurement is not calculated from the average of the air pressure, but has to be weighed using the gas consumption. This gas consumption is partly dependent on the temperature and wind speed. These two parameters show a correlation with air pressure.
For calculating the weighed average air pressure, the following basic principles have been used. The design of gas networks is based on a requested maximum day-capacity, which is a function of the mean daily temperature. It is assumed that the capacity varies linearly from a maximum at -12 °C to 10% of the maximum at 18 °C. At temperatures below -12 ° C and at temperatures above 18 ° C, the required capacity is temperature independent. In addition, the temperature is adjusted to the wind effect. For each 1 m / s average wind speed, the effective temperature is 0.1 °C lower. Using an effective temperature, we assume that the linear development of the capacity demand occurs between -14 º C and 18 ° C. We use this relationship as a measure of the gas consumption during one day at a given mean daily wind speed and temperature.

For the year 2006, the average atmospheric pressure was determined. In 2006, the average air pressure, according to KNMI in De Bilt data, was 1015.7 mbar. This is 2.4 millibars higher than the atmospheric pressure of 1.01325 bars used, and this produces an error in the gas measurement (volume conversion) in favor of the end user. Based on the above relationships the gas to the weighted error is calculated at approximately 0.37% in favour of the end user

<u>Conclusions from the applied theoretical model for the seven-degree method</u>

There are many factors affecting the accuracy (correctness) of the volume conversion of the measured volume of domestic conventional diaphragm gas meters. These factors are examined using a model based on several assumptions. These assumptions will be verified during the field trial (part 2 of the study). The results of the theoretical model are:

- For a significant proportion of the domestic consumers, the temperature of the gas entering the building is about 1 °C lower than the ground temperature.
- The heating of gas from the entry point of a building to the gas meter depends on the pipe diameter and the gas velocity.
- The most favourable situation for domestic end users is in case of the service line inside the building is limited to a short pipe length of about 1.5 meters. In this case, the heating effect results in a volume conversion error of about 1%. This difference is unfavourable for the end user.
- For high-rise buildings and high inside temperature - the worst case that will actually occur - heating effect can result in a temperature conversion error of about 6%. This difference is also unfavourable for the end user.
- For houses located at the periphery of the supply area of a district station in 30 millibars gas grids, errors in the volume conversion are introduced from about 0.1 to 0.2%. In all other cases and 100 millibars gas grids, the pressure effect on the volume conversion is negligible.

- The assumption about the atmospheric pressure in the Netherlands introduces an error in the volume conversion of about 0.4% (benefit of domestic consumers).

Laboratory testing to verify the “heat-up-length”.

To complete the theoretical analysis, as mentioned before, laboratory measurements investigating the effect of heating the gas inside the service line were performed.
The purpose of the measurements was to measure the heat exchange between the gas in the service line and the surrounding air. The results were used to determine the “heat-up-length”. The “heat-up-length” is the length in which the gas temperature is adjusted to 65% of the difference between ambient temperature and the original gas temperature.
Experimental conditions such as pipe diameter, temperature and flow rate of the gas flow were chosen to approach real practice situations.

For safety reasons and simplicity, all measurements are performed with air (nearly atmospheric pressure). The differences between natural gas and air are relatively small for this type of measurement. However, in the interpretation the difference in heat capacity (air: 1.3 kJ / (K M3N], natural gas 1.6 kJ / (K M3N) has to be taken into account. This means that the "cool-down-length" (or "heat-up-length") measured using air instead of gas, should be increased with approximately 25%.
A correction for the applied air pressure (air under nearly atmospheric pressure instead of gas with an overpressure of 30 mbar or 100 mbar), is also necessary.
Natural gas and air need the same magnitude of correction. This correction is less than 10% for the normal distribution pressures (30 and 100 mbar).

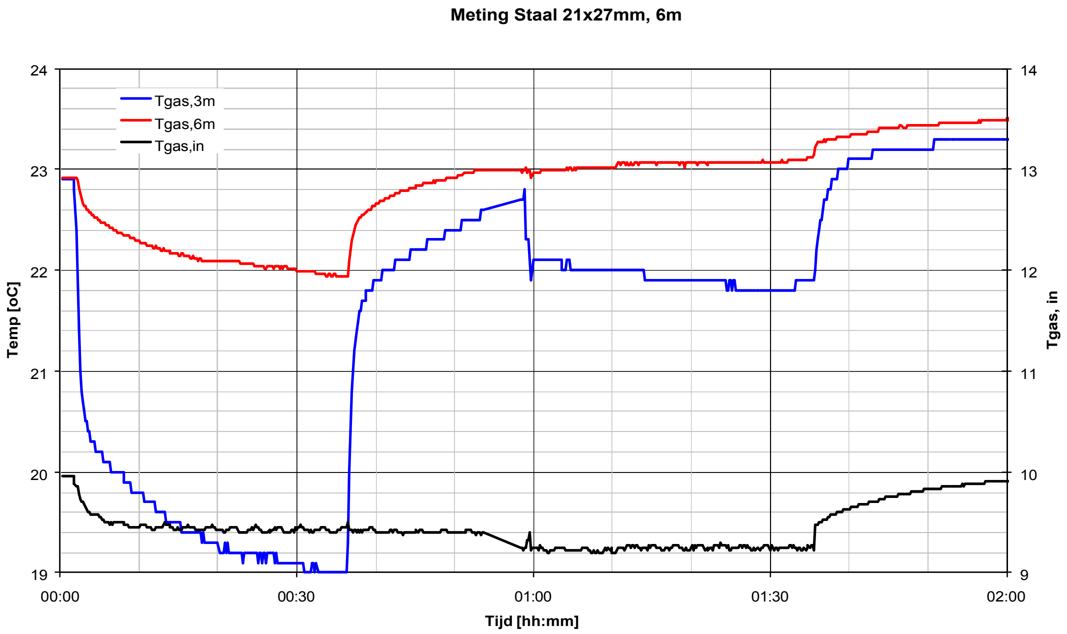

Figure 1 Example of the results of laboratory measurement on a steel service pipe.

In figure 1 the results of a measurement of heating and cooling of the gas in a ¾ inch steel pipe (at 3 meter (blue), at 5 meter (red) and at inlet (black)) as a function of time are given.

The "heat-up-lengths" resulting from the laboratory experiment are shorter than the heat-up-lengths calculated with the theoretical model. One explanation is that a lot of airflow (ventilation) occurred in the laboratory, so the heat exchange is encouraged. The results of the calculated heat exchange between the gas in the pipeline and the environment correspond with the "worst case", namely an environment with stagnant air.

In this case, the heat exchange of the gas with the surrounding stagnant air is slower. If the above calculations are performed with the corrected model (ventilation instead of stagnant air), the results of the calculations using the model are in agreement with results of the laboratory measurements. In practice, therefore the "heat-up-length", will be in between those of the model calculations and laboratory measurements, depending on the ventilation in the proximity of the gas pipeline. In part 2 this aspect will be analysed further.

From the results of part 1, the following conclusions can be drawn:

- From the theoretical consideration, it follows that the gas is heated while travelling thru the service pipe from the entry point to the gas meter.
- The "heat-up-length" calculated using the theoretical model and assuming stagnant air is about two times larger than that measured in the laboratory. These tests were conducted with ventilation around the pipe. If the ventilation is also taken into account the results of the model are similar to that of the laboratory measurements.
- The heating effect gives, depending on the type of building and the length of the gas pipeline from the entry point to the gas meter, rise to a temperature conversion error. The size of the temperature conversion error is less than 1%. This error is unfavourable for the domestic end users.
- The atmospheric pressure in the Netherlands gives a pressure conversion error of 0.4%. This difference is in favour of the domestic end user.
- The weighted average variation of all household conventional diaphragm gas meters in the Netherlands is between -0.17% (at maximum flow rate) and 0.92% (at low flow rate). This deviation is well within the Weights and Measures Act standards.

<u>Part 2 Field study between December 2007 and March 2008 on the influence of the temperature on the meter reading</u>

In order to check the theoretical findings under field conditions part 2 , field trials, of this investigation were performed. In this part the results are given.

In part 2 the actual deviation in the gas measurement due to heating of the gas has been established. To achieve this 26 sites are selected to carry out field research. The test sites were chosen in such a way that the variety of the gas installation and types of buildings in the Netherlands were represented.

Some examples of the adjusted gas meter including the data acquisition system are shown in figure 2.

Figure 2 Installed test equipment and adjustment of the diaphragm gas meter, left in meter closet, right in basement (pulse generator in black)

As result of a first global analysis of the measurement data, the temperature of the gas in the gas meter follows a high correlation with the temperature in the room in which the gas meter is installed. As described later, this is an extremely important observation for answering the main question.

To clarify the above observation, two situations are considered in more detail: location 23, where the temperature in the meter box is determined to a large extent by the outdoor temperature and location 25, where the influence of the outside temperature in the meter box is virtually absent.
These locations are the most extreme ones within the population of measurement locations. For location 23 the correlation between the gas temperature in the meter and the outside temperature is almost 1, with a (mean daily) temperature in the room where the gas meter is installed being 9-10 ° C higher than the (mean daily) outside temperature. At location 25, there is virtually no correlation and the (mean daily) temperature in the room where the gas meter was installed, is approximately 18 to 22 °C.

<u>The difference in measured volume during the registration period</u>

Based on the measured data, the difference in measured gas volume at each location during the registration period is determined. Each measurement includes the volume of gas passed through the meter and the different temperatures (in the gas meter, in the room of installation of the gas meter, temperature of the crawl space and the temperature of the service line at entry point. With this information, the average gas temperature was calculated. Using the information the measured volume can be corrected if the temperature differs from 7 °C (Qnormal).

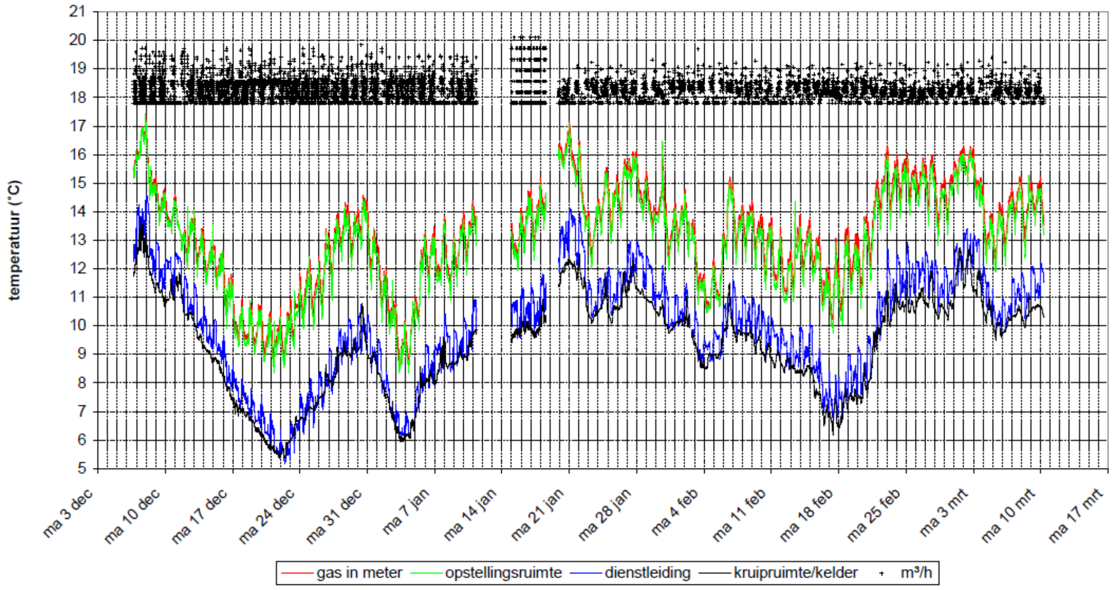

Figure 3 Example of the obtained registration of gas flow (black dots), temperature of the service line at entry point (black line), the temperature of the crawl space (or cellar)(blue line), temperature of the room of installation (green line) and the temperature of the gas in the meter (red line).

The total volume of gas passed during the measurement period follows from the simple summation of all measured volumes for each data point (Qmeasured). The weighted average gas temperature over the measurement period (Tgas, average) results from the difference between the corrected and uncorrected gas volumes. The results are summarized in Table 1 above. The deviation in calculated differences in volumes range from -0.43% (location 21 with a weighted average gas temperature of 8.1 °C) to -4.60% (location 25 with a weighted average gas temperature of 19.8 °C). The (average) volume difference of a combination of all measurement sites is -2.45% (weighted average gas temperature 13.8 °C).

Location	Qmeasured (m3)	Qnormal (m3)	Difference	Tgas,average (K)
1	561.8	555.3	-1.16%	283.4
2	359.4	351.5	-2.21%	286.3
3	850.8	827.9	-2.69%	287.7
4	284.2	271.4	-4.53%	292.8
5	805.2	785.8	-2.41%	286.9
6	113.6	111.5	-1.89%	285.5
7	673.8	667.8	-0.90%	282.7
8	1202.1	1177.7	-2.03%	285.8
9	425.3	406.3	-4.45%	292.6
10	1575.9	1547.8	-1.78%	285.1
11	972.7	952.9	-2.03%	285.8
12	646.8	618.6	-4.36%	292.4
13	178.0	170.2	-4.38%	292.4
14	704.5	686.2	-2.60%	287.4
15	760.5	731.2	-3.84%	290.9
16	331.1	316.3	-4.48%	292.7
17	581.6	574.1	-1.28%	283.7
18	482.9	469.2	-2.83%	288.1
19	765.8	741.5	-3.18%	289.0
20	52.6	51.3	-2.40%	286.9
21	1060.9	1056.3	-0.43%	281.3
22	902.6	882.9	-2.18%	286.3
23	193.7	190.7	-1.55%	284.5
24	131.8	126.5	-4.01%	291.4
25	659.1	628.8	-4.60%	293.0
26	387.5	380.2	-1.87%	285.4
Overall	15664.1	15279.9	-2.45%	287.0

Table 1 Outline of the measurement results and the calculated difference over the measurement period

The difference in measured volume calculated for a "standard" year; annual measuring error

The obtained results are valid for the measurement period during the winter of 2007 to 2008 only. To be able to support more general conclusions, it is necessary to "translate" the results to a "standard "year. For the "standard" year the average day temperatures of the past three decades (1971 to 2001) are used.
During the relatively cold period from December to February, about 40% of the annual gas consumption is used. The remaining 60% is consumed during the relatively warm period from March to November. Depending on the influence of outside temperature on the gas temperature in the gas meter, the volume difference of a "standard" year will differ from the

measured volume difference measured in the applied testing period.

Location	Difference during measurement period	Difference scaled to "standard" year
1	-1.16%	-1.56%
2	-2.21%	-2.73%
3	-2.69%	-3.11%
4	-4.53%	-4.55%
5	-2.41%	-2.88%
6	-1.89%	-2.49%
7	-0.90%	-1.72%
8	-2.03%	-2.59%
9	-4.45%	-4.49%
10	-1.78%	-2.40%
11	-2.03%	-2.59%
12	-4.36%	-4.42%
13	-4.38%	-4.43%
14	-2.60%	-3.03%
15	-3.84%	-4.01%
16	-4.48%	-4.52%
17	-1.28%	-2.02%
18	-2.83%	-3.21%
19	-3.18%	-3.48%
20	-2.40%	-2.88%
21	-0.43%	-1.37%
22	-2.18%	-2.71%
23	-1.55%	-2.23%
24	-4.01%	-4.14%
25	-4.60%	-4.61%
26	-1.87%	-2.47%

Table 2 Estimation of the differences in gas volume for all locations scaled to a “standard” year.

The differences of the estimated gas volumes scaled to a “standard” year ranges from -1.37% (location 21 with a weighted average gas temperature of 10.8 °C) to -4.61% (location 25 with a weighted average gas temperature of 19.9 °C). The mean difference, also scaled to a “standard” year of all measurement data combined is -2.90% (weighted average gas temperature 15.1 °C).

<u>The measurement differences related to types of the houses and characteristics of the in house gas installation in the Netherlands.</u>

For the interpretation of the results, a classification of measurement locations was made based on the characteristics expected to have a strong influence on the temperature of the gas in the gas meter.

The characteristics used to differentiate are:
- High-rise building / one family house
- First storey (downstairs) / upstairs (in high-rise building)
- Gas meter cupboard to side wall / indoor
- Urban / rural areas (with only one family houses)
- Service line crossing heated / unheated rooms

Note: The last characteristic is not reflected in this study,because in all 26 monitoring locations the service line crosses unheated rooms. There is still a difference between lines in (relatively) cold crawl spaces / basements and outside risers and pipelines. The first ones, although crossing unheated rooms are reltively warm by adjacent heated rooms.

All this information is used to analyse the influence of the building type, place of the meter inside the building, the temperature in the direct surrounding of the gas meter and the in house pipe length on the volume conversion error. From this analysis some interesting conclusions can be drawn. These are:

- For both high-rise buildings as one family houses, a clear distinction between an unheated meter closet and an inside (more or less) heated closet is seen
- For one family houses, the difference in volume after conversion is almost independent from the type of building, but mainly affected by the temperature of the surrounding of the meter and gas pipeline.
- In detached houses, the gas meter is always situated in a place where it is little to no heat at all. The convection error in the field trials, due to the low thermal impact is relatively low

Based on the results of the analysis a classification of the different residential house types can be made. For every type of building a typical measurement error related to a “standard” year can be given. See table 3

House type	Typical measurement error in a "Standard" year compared to the seven-degree method (%)
High-rise building with meter closet outside	2 - 2.5
High-rise building with meter closet inside	4 - 4.5
One family house with unheated meter closet	1.5 - 3
One family house with heated closet	3 - 4.5
Detached house	1.5 - 3

Table 3 Typical measurement error in a “standard” year compared to the seven-degree method

<u>Influence of individual characteristics of the house types</u>

It follows that the temperature of the gas in the gas meter is almost exclusively determined by the temperature in the room where the meter is installed.

From extensive analysis of the data no other general characteristic of the houses were derived that showed a clear influence on the measurement error.

High-rise buildings or one family houses

The assumption that in the upper floor of high-rise buildings the gas temperature is significantly higher (weighted average) due to the heating of the gas in the in-walled riser is not confirmed by the results of the field trial. In general, the riser is installed in a shaft that is formed by above the other situated meter closets on each floor. The temperature of the riser is more or less equal to that of the meter closet and gas meter. Due to the efficient heat exchange in the gas meter, the temperature of gas in the gas meter is almost equal to the room temperature in the meter closet.

Urban or rural areas

The distinction between urban and rural areas was made based on the thought that the ground temperature can be higher in urban areas than in rural areas. Upon entering the house, the gas temperature will adopted almost the soil temperature. In the field trial, three rural areas locations (7, 8 and 19) were included. At all three locations, the wall temperature of the service when entering the house (crawl space or basement) is recorded. The recordings of the temperature of the gas in the gas meter show that this temperature practically follows the temperature in the surrounding air. The correlation of gas temperature with the soil temperature is absent, except for the relationship between outdoor temperature and the temperature in the basement / crawl space. For example at location 11 is the temperature of the service line at the entry point is lower than the temperature in the crawl space. The results of the field measurements do not show a clear effect of the lower soil temperature on the gas temperature in the gas meter.

Meter closet close to the outer wall or meter closet indoor

The measurements in the field test show a dominant influence of the installation room temperature on the temperature of the gas in the gas meter.
Positioning of the meter in a room or closet with one or more outer walls will generally lead to a lower temperature in the meter and thus a lower temperature of the gas.

Service line (or riser) crossing heated or unheated rooms

As was discussed before that the temperature of the gas in the gas meter was barely affected by the temperature of the gas at the entry point. The heat transfer through the service line in the meter installation room and through the gas meter is such, that the gas temperature within two degrees is equal to the temperature in the meter installation area, regardless of the flow temperature.

On / off boiler control or modulating burner

On / off boiler control would be expected to lead to a lowering effect on the gas temperature in the gas meter, due to the greater gas flow compared to those cases where a modulating burner is used in a boiler. The results of the field test do not show a visible effect as a results of the type of the boiler control.

Habitation permanently / intermittently

For permanent habitation, a flatter firing pattern compared to intermittent habitation (two heating periods per day) can be expected. A flatter firing pattern would influence the gas temperature. However, there is no effect in the results visible from the habitation.

Differences from the seven-degree method for the total of housing stock in the Netherlands

Data on the factors that determine the measured differences from the seven-degree method (see above, in particular the temperature in the meter installation area) are missing. Based on fragmentary data an estimated distribution of the Dutch housing stock to high rise / one family house (29% / 71%) and extension / detached (54% / 17% percent point to 71%).
The total number of houses in the Netherlands with a connection to the gas grid and where gas is used for domestic heating is 6.15 million (1.78 million
high-rise buildings, one family houses 3.32 million and 1.05 million detached houses).
For the distribution external / internal meter closets, data is lacking. It is expected that external meter closets are not common (estimated at no more than 15% of all cases). This 15% is based on the fact that external meter closets are only seen in gallery flats,
built until the 70-ies. Moreover, the choice of 15% has only a low impact on the results.
Further more, due to lacking data, it is assumed that 25% of the one family houses have a unheated meter closet
Taking into account the slight decline of the gas consumption over the years, the following consumptions are estimated for a normal year:

High-rise building (per household)	1200 m^3/annum
One family house, extension	1800 m^3/annum
Detached houses	2500 m^3/annum

Based on a combination of the above-mentioned information an estimation of the total measurement error for the Dutch retail market can be made.
The application of the seven-degree method leads to an overestimation of
2.6 - 3.9% of the total amount of gas for all domestic end consumers in the Netherlands. This corresponds to an amount of 275 to 415 million m^3 per annum.

Conclusions

The seven-degree method assumes the following:

- gas temperature in the gas meter is 7 º C;
- nominal delivery pressure (pressure) is 28 millibars;
- Atmospheric pressure is 1.01325 bar.

This research has shown that the actual gas temperature in the gas meter can significantly vary from the assumed value of 7 °C. The in the seven-degree method assumed gas temperature of 7 °C can, in extreme situations (depending on the location of the gas meter in the house), in average deviate more than +5% (based on absolute temperature). By the assumption that the gas pressure is constant (28 millibars) and the atmospheric pressure is 1.01325 bars, an error in the volume conversion is introduced which is significantly smaller than the "temperature error". An important advantage of applying the seven-degree method for domestic end users using a diaphragm gas meter is that the gas meter reading corresponds with the converted volume to normal conditions. The administrative process is rather simple and an administrative correction is not necessary.

The measurement errors can be significantly reduced, if the average gas temperature (7 °C) as assumed in the seven-degree method, is changed to a temperature closer to the actual average gas temperature (for instance 15 °C). In this case, the average measurement error for all types of houses / households is relative small. However the differences between the households will in this case remain.

An administrative correction to convert to normal m^3 is in this case necessary. A correction is also necessary for conversion from the supply pressure (from 28 millibars) to atmospheric pressure.

Based on the results of the research performed by Kiwa Gas Technology, the following main conclusions can be drawn:

1. The size of the difference between the measured quantity of gas (with application of the seven-degree method) and the actually delivered gas quantity is mainly determined by the location of the gas meter in the building and the location of the gas meter (temperature effect).

2. Based on field research in 26 houses in the heating season 2007/2008 a estimation of the measurement error caused by the temperature effect in the application of the seven-degree method for “standard” year was made. The measuring errors in the houses in this study are in all cases unfavourable for the end customer and amounts from 1.6 to 4.6% annually.

3. The measurement deviation due to the temperature effect depends on the type of house. Based on the results of the fieldwork the following typical measurement deviations were derived:

House type	Typical measurement error in a "Standard" year compared to the seven-degree method (%)
High-rise building with meter closet outside	2 - 2.5
High-rise building with meter closet inside	4 - 4.5
One family house with unheated meter closet	1.5 - 3
One family house with heated closet	3 - 4.5
Detached house	1.5 - 3

4. Based on the results of field studies and an estimated distribution of house types in the housing stock in Netherlands it is concluded that the total measurement error for all domestic gas customers in the Netherlands amounts 275 to 415 million m^3 per “standard” year (2.6 to 3.9%), unfavourable for the end customer.

5. The (supposed) gas pressure also determines the accuracy of gas volume measurement. The difference between the mean delivery pressure and atmospheric pressure compared to the in the seven-degree method assumed delivery pressure (28 mbar) and atmospheric pressure (1.01325 bar) is relatively small. The measurement error due to the delivery pressure is estimated at less than + / - 0.2% in the advantage or disadvantage of the customer. For the atmospheric pressure the error is also small (<0.2%), however systematically in favour of the customer.

Postscript
I thank my colleagues who all were very willing to support me with all data necessary to write this paper. My special thanks go to the Dutch Competition Authority who granted Kiwa Gas Technology to perform this study and published the results on their website.