INTERNATIONAL STANDARD

ISO 15112

Second edition
2011-07-15

Natural gas — Energy determination

Gaz naturel — Détermination de l'énergie

Reference number
ISO 15112:2011(E)

ISO copyright office
Case postale 56 • CH-1211 Geneva 20
Tel. + 41 22 749 01 11
Fax + 41 22 749 09 47
E-mail copyright@iso.org
Web www.iso.org

Published in Switzerland

Contents

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 15112 was prepared by Technical Committee ISO/TC 193, *Natural gas*.

This second edition cancels and replaces the first edition (ISO 15112:2007), which has been technically revised.

Introduction

Since the early 1800s, it has been general practice for manufactured gas and, subsequently, natural gas to be bought and sold on a volumetric basis. Much time and effort has therefore been devoted to developing the means of flow measurement.

Because of the increasing value of energy and variations in gas quality, billing on the basis of thermal energy has now become essential between contracting partners and the need to determine calorific value by measurement or calculation has led to a number of techniques. However, the manner in which calorific value data are applied to flow volume data to produce the energy content of a given volume of natural gas has been far from a standardized procedure.

Energy determination is frequently a necessary factor wherever and whenever natural gas is metered, from production and processing operations through to end-user consumption. This International Standard has been developed to cover aspects related to production/transmission and distribution/end user. It provides guidance to users of how energy units for billing purposes are derived, based on either measurement or calculation or both, to increase confidence in results for contracting partners.

Other standards relating to natural gas, flow measurement, calorific value measurement, calculation procedures and data handling with regard to gas production, transmission and distribution involving purchase, sales or commodity transfer of natural gas can be relevant to this International Standard.

This International Standard contains ten informative annexes.

Natural gas — Energy determination

1 Scope

This International Standard provides the means for energy determination of natural gas by measurement or by calculation, and describes the related techniques and measures that are necessary to take. The calculation of thermal energy is based on the separate measurement of the quantity, either by mass or by volume, of gas transferred and its measured or calculated calorific value. The general means of calculating uncertainties are also given.

Only systems currently in use are described.

NOTE Use of such systems in commercial or official trade can require the approval of national authorization agencies, and compliance with legal regulations is required.

This International Standard applies to any gas-measuring station from domestic to very large high-pressure transmission.

New techniques are not excluded, provided their proven performance is equivalent to, or better than, that of those techniques referred to in this International Standard.

Gas-measuring systems are not the subject of this International Standard.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 6976, *Natural gas — Calculation of calorific values, density, relative density and Wobbe index from composition*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1
accuracy of measurement
closeness of the agreement between a measurement result and a true value of the measurand

[ISO 14532:2001]

3.2
adjustment
⟨of a measuring instrument⟩ operation of bringing a measuring instrument into a state of performance suitable for its use

NOTE Adjustment may be automatic, semi-automatic or manual.

3.3

assignment method

⟨energy determination⟩ method to derive a calorific value to be applied to the gas passing specified interfaces having only volume measurements

3.4

availability

probability, at any time, that the measuring system, or a measuring instrument forming part of the measuring system, is functioning according to specifications

[EN 1776:1998]

3.5

bias

systematic difference between the true energy and the actual energy determined of the gas passing a gas-measuring station

3.6

calibration

set of operations that establish, under specified conditions, the relationship between values of quantities indicated by a measuring instrument or measuring system, or values represented by a material measure or a reference material, and the corresponding values obtained using working standards

[ISO 14532:2001, 2.5.2.2]

3.7

superior calorific value

energy released as heat by the complete combustion in air of a specified quantity of gas, in such a way that the pressure, p_1, at which the reaction takes place remains constant, and all the products of combustion are returned to the same specified temperature, T_1, as that of the reactants, all of these products being in the gaseous state except for water formed by combustion, which is condensed to the liquid state at T_1

[ISO 14532:2001, 2.6.4.1]

3.8

inferior calorific value

energy released as heat by the complete combustion in air of a specified quantity of gas, in such a way that the pressure, p_1, at which the reaction takes place remains constant, and all the products of combustion are returned to the same specified temperature, T_1, as that of the reactants, all of these products being in the gaseous state

[ISO 14532:2001, 2.6.4.2]

3.9

calorific value station

installation comprising the equipment necessary for the determination of the calorific value of the natural gas in the pipeline

3.10

adjusted calorific value

calorific value measured at a measuring station compensated for the time taken for the gas to travel to the respective volume-measuring station

3.11

corrected calorific value

result of correcting a measurement to compensate for systematic error

3.12
declared calorific value

calorific value that is notified in advance of its application to interfaces for the purpose of energy determination

3.13
representative calorific value

calorific value which is accepted to sufficiently approximate the actual calorific value at an interface

3.14
charging area

set of interfaces where the same method of energy determination is used

3.15
conversion

determination of the volume under reference conditions from the volume under operating conditions

3.16
correction

value added algebraically to the uncorrected result of a measurement to compensate for systematic error

NOTE 1 The correction is equal to the negative of the estimated systematic error.

NOTE 2 Since the systematic error cannot be known perfectly, the correction cannot be complete (see Annex I).

3.17
correction factor

numerical factor by which the uncorrected result of a measurement is multiplied to compensate for a systematic-error object

NOTE Since the systematic error cannot be known perfectly, the correction cannot be complete (see Annex I).

3.18
determination

set of operations that are carried out on an object in order to provide qualitative or quantitative information about this object

NOTE In this International Standard, the term “determination” is only used quantitatively.

3.19
direct measurement

measurement of a property from quantities which, in principle, define the property

NOTE For example, the determination of the calorific value of a gas using the thermoelectric measurement of the energy released in the form of heat during the combustion of a known amount of gas.

[ISO 14532:2001, 2.2.1.2]

3.20
energy

product of gas quantity (mass or volume) and calorific value under given conditions

NOTE 1 The energy may be called energy amount.

NOTE 2 Energy is usually expressed in units of megajoules.

3.21
energy determination

quantitative determination of the amount of energy of a quantity of gas based either on measurement or calculation using measured values

3.22
energy flow rate
energy of gas passing through a cross-section divided by time

NOTE Energy flow rate is usually expressed in units of megajoules per second.

3.23
fixed assignment
application without modification of the calorific value measured at one specific calorific-value-measuring station, or the calorific value declared in advance, to the gas passing one, or more, interfaces

3.24
gas transporter
company that conveys gas from one place to another through pipelines

3.25
grid simulation
calculation of a set of pressures and flow rates in a pipeline or a grid on the basis of given topology data, values of the flow rates at the inlet and outlet points and of the pressure and temperature at various points of the pipeline(s) by means of a mathematical model

NOTE The objective of any grid simulation is to yield information about a future state of gas pressures and flows. The result of the simulation is an estimation of the state of the gas flow.

3.26
interface
place on a pipe used for the transportation or supply of gas at which there is a change of ownership or physical custody of gas

NOTE Generally, an interface has an associated measuring station.

3.27
local distribution company
LDC
company that delivers gas to industrial, commercial and/or residential customers

3.28
measuring station
installation comprising all the equipment, including the inlet and outlet pipework as far as the isolating valves and structure within which the equipment is housed, used for gas measurement in custody transfer

[EN 1776:1998]

3.29
measuring system
complete set of measuring instruments and auxiliary equipment assembled to carry out specified measurements

NOTE Adapted from ISO/IEC Guide 99:2007, 3.2.

3.30
measuring instrument
device intended to be used for making measurements, alone or in conjunction with one or more supplementary devices

[ISO/IEC Guide 99:2007, 3.1]

3.31
plausibility
property of a value to be within reasonable limits

3.32
producer

company that extracts raw natural gas from reservoirs which, after processing and (fiscal) measurement, is supplied as dry natural gas to the transportation system

3.33
regional distributor

company that delivers gas to local distribution companies and/or industrial, commercial or residential customers

3.34
residential customer

person whose occupied premises are supplied with gas, wholly or in part, such gas not being used for any business purpose, commercial or industrial

3.35
systematic error

mean that would result from an infinitive number of measurements of the same measurand carried out under repeatability conditions minus a true value of the measurand

3.36
traceability

property of the result of a measurement or the value of a standard whereby it can be related to stated references, usually national or International Standards, through an unbroken chain of comparisons all having stated uncertainties

NOTE This chain of comparisons is called a traceability chain.

3.37
uncertainty

parameter, associated with the result of a measurement, that characterizes the dispersion of the values that could reasonably be attributed to the measurand

3.38
variable assignment

application of a calorific value for an assignment procedure based on measurement(s) at calorific value station(s) to the gas passing one, or more, interfaces

NOTE That applied calorific value may take into account the time taken for the gas to travel from the calorific value station to the respective volume-measuring stations and other factors, to derive an average calorific value for a network, a state reconstruction of the variation of calorific values through a network, etc.

3.39
zero floating point

position in a grid conveying gas where there is a boundary with different gas qualities on either side

3.40
non-plausible data

measurement data that are obviously wrong taking into account the measurement situation at a measuring station and the gas flow situation

4 Symbols and units

Symbol	Meaning	SI unit	USC unit
E	energy	MJ	kWh
e	energy flow rate	MJ/s	kWh/h
H	calorific value	MJ/m^3; MJ/kg	kWh/m^3

NOTE 1 Where the calorific value is in megajoules per cubic metre and the gas volume is in cubic metres, or where the calorific value is in megajoules per kilogram and the gas mass is in kilograms, then the calculated energy is in megajoules.

Where the calorific value is in kilowatt-hours per cubic metre and the gas volume is in cubic metres, or where the calorific value is in kilowatt-hours per kilogram and the gas mass is in kilograms, then the calculated energy is in kilowatt-hours.

To convert the number of megajoules to the number of kilowatt-hours, divide the number by 3,6.

Symbol	Meaning	SI unit	USC unit
M	mass	kg	t
p	pressure (absolute)	Pa, kPa	bar, mbar
Q	quantity of gas	m^3, kg	t

NOTE 2 When the quantity is given in cubic metres, it is necessary that it should be qualified by temperature and pressure.

Symbol	Meaning	SI unit	USC unit
q_v	volume flow rate	m^3/h, m^3/s	
q_m	mass flow rate	kg/s, kg/h	
T	temperature (absolute)	K	
t	time	s, h, d	s, h, d
V	volume (gas)	m^3	
Z	compression factor		
ρ	density	kg/m^3	
ϑ	temperature	°C	°F

Subscripts

i	inferior calorific value
j	number of time intervals
n	normal reference conditions (273,15 K; 101,325 kPa)
r	ISO-recommended standard reference conditions (288,15 K; 101,325 kPa)
s	superior calorific value

5 General principles

The quantity of energy, E, contained in a given quantity of gas, Q, is given by the multiplication of the calorific value, H, by the respective quantity of gas.

Energy may be either measured directly (see Figure 1) or calculated from the quantity and the calorific value of the gas (see Figure 2).

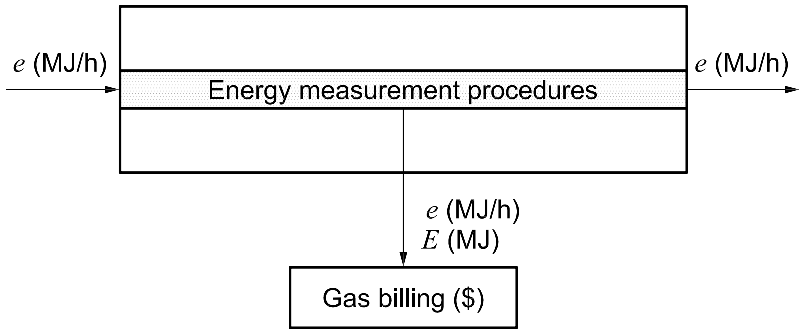


Figure 1 — Energy-measurement scheme

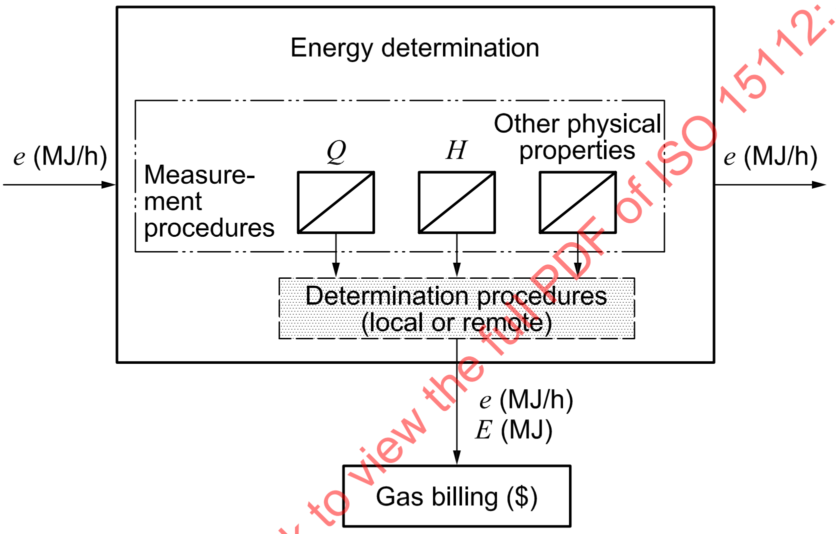


Figure 2 — Energy-determination scheme

Generally, the quantity of gas is expressed as a volume and the calorific value is on a volumetric basis. In order to achieve accurate determinations of energy, it is necessary that both the gas volume and calorific value be under the same reference conditions. The determination of energy is based either on the accumulation over time of calculation results from consecutive sets of calorific values and the concurrent flow rate values, or on the multiplication of the total volume and the representative (assigned) calorific value for that period.

Especially in situations of varying calorific values and when flow rates are determined at a place different from that of the (representative) calorific value, the effect on the accuracy caused by the difference in time between the determination of the flow rate and the calorific value shall be considered (see Clause 11).

The gas volume may either be measured and reported as the volume under the ISO-recommended standard reference conditions or be measured under some other conditions and converted to an equivalent volume under the ISO-recommended standard reference conditions, using an appropriate method of volume conversion. The method of volume conversion used at a specific gas-volume-measuring station may require gas quality data determined at other places. For the purpose of this International Standard, the ISO-recommended standard reference conditions of 288,15 K and 101,325 kPa, as defined in ISO 13443, should be used.

NOTE For the gas supply, other conditions can be used, corresponding to national standards or laws. Methods for conversion between different conditions for dry natural gases are given in ISO 13443.

The calorific value may be measured at the gas-measuring station or at some other representative point and assigned to the gas-measuring station. It is also possible for the quantity of gas and the calorific value to be expressed on a mass basis.

This general principle of energy determination is extended in Clause 10 to those cases when the quantity of gas is expressed on either a volumetric or a mass basis.

To achieve the calculation of the quantity of energy of the gas passing a gas-measuring station over a period of time, the methods of energy determination in Clauses 7 to 10 are used. Such methods involve an integration over the time period; that integration may be

- of the energy flow, or
- of the gas flow rate over time to obtain the quantity of gas, which is then multiplied by the representative calorific value.

The method of integration may depend on contractual agreements or national legislation.

The general principles of energy determination in Clauses 7 to 10 are independent of the method with which the integrations are carried out. The method of integration influences the uncertainty of the determined energy; these effects are considered in Clause 11.

6 Gas measurement

6.1 General

The types of measuring devices and methods used in real measuring stations depend among other things on

- the respective national requirements,
- the flow rate,
- the commercial value of the gas,
- the gas quality variations,
- the need for redundancy, and
- the instrument specification.

Only proven methods and measuring devices/products used at the respective interfaces should be used. An overview of the techniques and procedures currently used in different countries is shown in Annex A.

Methods used for flow and calorific value measurement shall be in accordance with standards, contractual agreements and/or national legislation, as appropriate.

Action should be taken to identify and reconcile systematic effects. For example, use of different national standards, regulations and/or operating procedures can introduce systematic differences; contract partners should determine the appropriate means to overcome these differences.

The quality of the measurement results, in general, depends on the following factors:

- operating conditions;
- maintenance frequency and quality;
- calibration standards;

- sampling and clean-up;
- changes in gas composition;
- ageing of measurement devices.

A high accuracy can be achieved if the requirements fixed by the manufacturers and by officials are met and all operating procedures for operating, calibration and maintenance are strictly observed.

6.2 Volume measurement

The volume flow-metering system of a natural-gas-measuring station consists of one or more meter runs. Generally, the meters measure the gas volume flow under actual operating conditions. Standards for orifice meters (ISO 5167-1) and turbine meters (ISO 9951) exist.

The selection of a flow-metering system for a specific application depends, as a minimum, on the following:

- conditions of flow;
- flow-measuring range;
- operating conditions, especially operating pressure;
- acceptable pressure loss;
- required accuracy.

For natural-gas volume flow measurement, the instruments mostly used at the interfaces 1 to 6 (see 7.1) are shown in Annex A.

6.3 Calorific value measurement

6.3.1 Measurement techniques and sampling

A calorific-value measuring system consists of a sampling system and a measurement device taken from one of the following groups:

- direct measurement (e.g. by combustion calorimeters);
- inferential measurement [e.g. by a gas chromatograph (GC)];
- correlation techniques.

To achieve a high accuracy of calorific value measurement, representative sampling is required. Guidelines are given in ISO 10715.

Depending on

- the measuring system,
- the operating procedures,
- the fluctuation of composition of the gas, and/or
- the quantity of gas delivered,

one of the following sampling techniques can be used:

a) continuous direct sampling;

b) periodical spot sampling;

c) incremental sampling.

Samples are taken for either online analysis or offline analysis.

6.3.2 Direct measurement — Calorimetry

With direct measurement, natural gas at a constant flow rate is burned in an excess of air and the energy released is transferred to a heat-exchange medium resulting in an increase in its temperature. The calorific value of the gas is directly related to the temperature increase.

Calorimetry is used for interfaces 1 to 3 and 5. ISO 15971 gives details of the measurement of combustion properties.

6.3.3 Inferential measurement

With inferential measurement, the calorific value is calculated from the gas composition in accordance with ISO 6976.

The most widely used analytical technique is gas chromatography. Procedures for the determination of the composition with defined uncertainty by gas chromatography are given in ISO 6974 (all parts). GC measurement is used at interfaces 1 to 3 and 5.

6.3.4 Correlation techniques

Correlation techniques make use of the relationships between one or more physical properties and the calorific value of the gas. Also, the principle of stoichiometric combustion can be used.

6.4 Volume conversion

6.4.1 General

Conversion of a volume of natural gas measured under operating conditions to a volume under reference or base conditions is based either on a gas pressure, temperature and compression factor (pTZ-conversion) or on gas densities under operating and base conditions (density conversion).

For details, see Annex C, Clauses E.1 and E.2, ISO 12213 (all parts) and EN 12405-1.

6.4.2 Density

The density under reference conditions (sometimes referred to as normal, standard or base density) can be required for conversion of volume data. Density under operating conditions may be measured for mass-flow determination and volume conversion.

Details are given in ISO 15970.

6.4.3 Pressure and temperature

Pressure and temperature measurements can be necessary for the conversion of the gas volume under operating conditions to a volume under standard reference or normal conditions. Details are given in ISO 15970.

6.4.4 Compression factor

For gas volume conversion, the compression factor is

- calculated from the gas composition using a molar analysis (see Clause E.2 and ISO 12213-2),
- calculated using physical properties and some constituents (see Clause E.1 and ISO 12213-3), or
- measured by a Z-meter.

Details are given in ISO 15970.

The compression factor under reference conditions may also be calculated according to ISO 6976. Depending on the quantity of gas delivered and variations in pressure, temperature and gas composition at the specific metering point, the compression factor either may be set constant or shall be calculated from time to time.

The user of this International Standard shall take account of the gas composition, especially with respect to the molar relationships of the higher hydrocarbons to each other and at high pressure. Depending on the gas composition and the pressure, methods for calculating the Z-factor on the basis of ISO 12213-2, rather than on the basis of ISO 12213-3, should be considered to avoid systematic errors.

6.5 Calibration

Quality of calibrations has a significant impact on the trueness of a measurement result. The frequency of the calibrations shall be determined according to the stability of the measurement devices. Calibrations should be traceable to appropriate standards and reference materials.

A representative calibration should be performed under conditions close to those at which the meter operates. For calorific measurement devices, calibration gases that are close to the expected calorific value or composition of the gas to be measured (see, for example, ISO 15971) should be used.

If, upon verification of any measuring instrument used for energy-determination purposes, an agreed deviation between the instrument reading and the corresponding value realized by a standard is exceeded, a calibration of the measuring instrument shall be carried out in order either

- to make adjustments to the instrument that establishes the smallest possible difference between the measured value and the value given by the standard, or
- to derive a correction that is applied to the measured value for subsequent periods to produce the correct value.

The actual process of adjustment or correction may be either manual or automatic, depending on the type of instrument.

If, at the calibration of the calorific-value-measuring device, a difference between measured and certified values occurs, for subsequent periods a correction of the measured values or adjustment shall be performed.

6.6 Data storage and transmission

All relevant data for determining energy shall be securely stored. The length of storage time and place of storage shall take into account national regulations and/or contractual conditions.

The data incorporate

- information contributing to and/or consisting of the amount of energy supplied and, where available,
- information on the data validity or the functioning of the metering station (hardware and software).

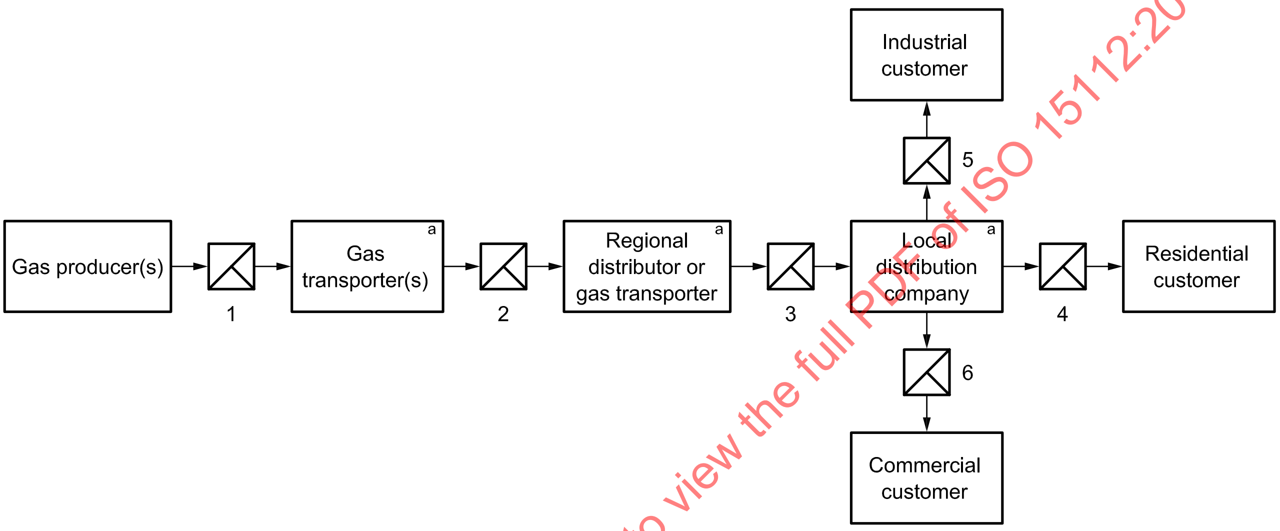
For data transfer, safe procedures shall be taken to ensure the integrity of the data.

7 Energy determination

7.1 Interfaces

Natural gas custody transfer between contract parties is, in general, performed from the producer(s) or gas storages to the end user via intermediate stages involving some or all of the following:

- gas transporter(s);
- regional distributors;
- local distribution company(ies).

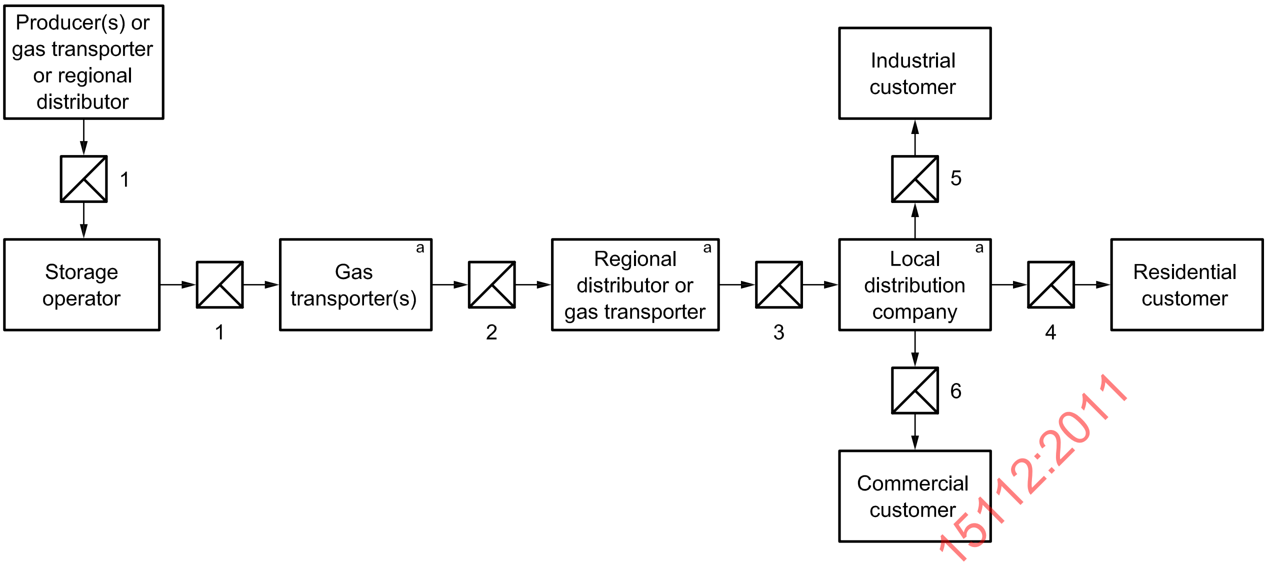


Key

1 to 6 interfaces

[a] If this entity exists.

Figure 3 — Possible interfaces for energy determination from producer(s) to end users



Key

1 to 6 interfaces

[a] If this entity exists.

Figure 4 — Possible interfaces for energy determination from producer(s) to end users including gas storages

The boxes numbered 1 to 6 in Figures 3 and 4 represent the different interfaces within a delivery chain; they may consist physically of a real measuring station or may be regarded only as virtual interfaces without any measurement to define the point of delivery or redelivery within contractual situations. Energy determination in a delivery chain between contract parties is performed at interfaces 1 to 6 (see Figures 3 and 4), often also named points of delivery and/or points of redelivery. Figure 3 shows the delivery chain from the producer to the end user; Figure 4 includes, additionally, a storage operator, who usually stores gas for producers, gas transporters or regional distributors for future take-off. The kinds of interfaces may differ within the different countries. They may be used as gas-billing interfaces, if they are actual measuring stations.

Three different models of different delivery situations are given as examples.

a) The gas transporter supplies gas directly to an industrial customer.

For energy determination at interface 5, the gas volume is measured at interface 2 or 5; because there is no regional distributor/storage company or local distribution company (LDC) involved, the calorific value measured at interface 2 can be used if nearly constant gas quality (see Figure B.1) can be expected.

b) The gas producer supplies gas directly to an industrial customer.

The pipeline system is used by several gas transporters and regional distributors for transportation; LDCs are not involved. On its way to the industrial customer, no gas quality changes occur. For energy determination at interface 5, the gas volume is measured at interface 5 and the calorific value at, for example, interfaces 5, 3 or 2.

c) The LDC supplies gas to the end user, commercial and industrial customer.

The LDC is supplied by a regional distributor, or gas transporter or storage company. For energy determination, volume measurement is performed at interfaces 4 to 6. Due to different gas qualities (see Figure B.3), the regional distributor operates a state reconstruction programme for calorific-value determination at interface 3; that calorific value is taken by the LDC for energy determination at interfaces 4 to 6.

The method of energy determination depends on a number of important factors; they shall be taken into account for the suitable energy-determination strategy to support the user of this International Standard to perform a correct energy determination. They include

- grid topology,
- flow directions,
- take-off structure or consumption profile,
- course of calorific value,
- technical equipment,
- contractual requirements, and
- national regulations.

It is the main goal of the methods given in 7.2

a) to support a satisfactory energy balancing within the transportation grid, and

b) to provide a justified energy determination at interfaces,

taking into account economic aspects.

7.2 Methods of energy determination

7.2.1 Direct determination of energy

For direct measurement (see Figure 5), individual physical parameters (e.g. Q, H) are not measured. The energy flow and energy quantity are calibrated and shown at the measuring point. At the time of preparation of this International Standard, direct energy-measurement instruments have entered the marketplace, but they are not yet proven technology for custody transfer. No International Standards exist at the moment.

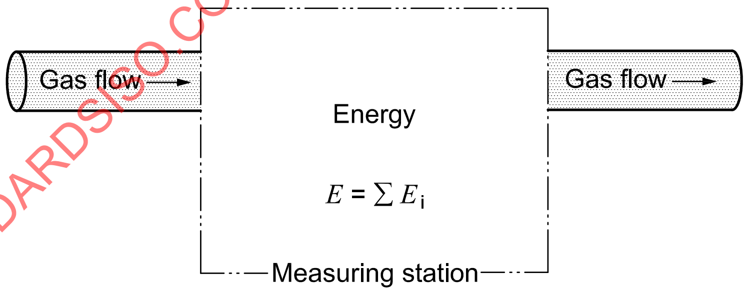


Figure 5 — Direct determination of energy

7.2.2 Indirect determination of energy

For indirect energy determination, the energy is determined on the basis of previously measured or calculated values for volume/mass, calorific value and other entities.

7.2.2.1 Measurement of volume or mass and calorific value at the same station

For indirect determination of energy, the volume or mass, calorific value and additional physical entities, such as CO_2, density, etc., of the gas are measured separately in a measuring station (see Figure 6); the measurement devices are individually calibrated. The volume flow rate and energy quantity are typically displayed at the measuring point. For large gas quantities Q_1 and Q_2, for example at border crossings, it can be necessary to determine the calorific values H_{S1} and H_{S2} by means of two calorific-value measurement devices at each station (see Figure 15).

Another method is to collect the calorific value and volume data in the measuring station and to transmit the data to a different central energy-determination station where energy flow and energy quantity are determined.

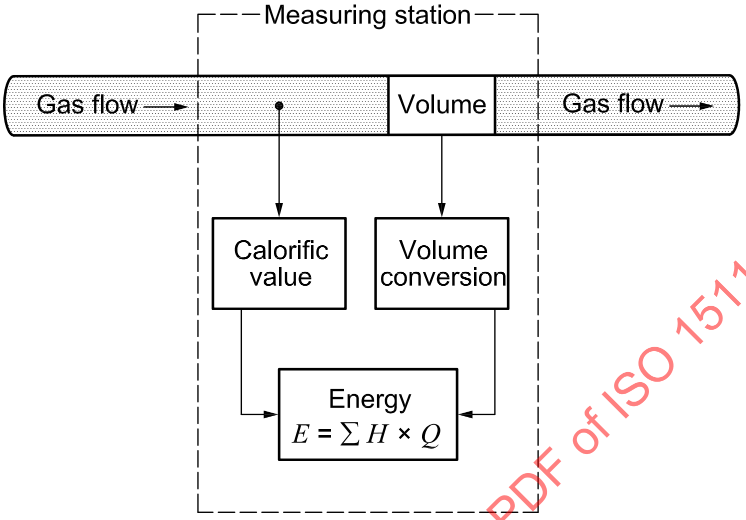


Figure 6 — Local online calorific value measurement

Due to the local gas-quality situation and for economical reasons, it is sometimes of use to take samples of gas (time- or flow-controlled) within the measuring station and to determine the calorific value at a different place (see Figure 7).

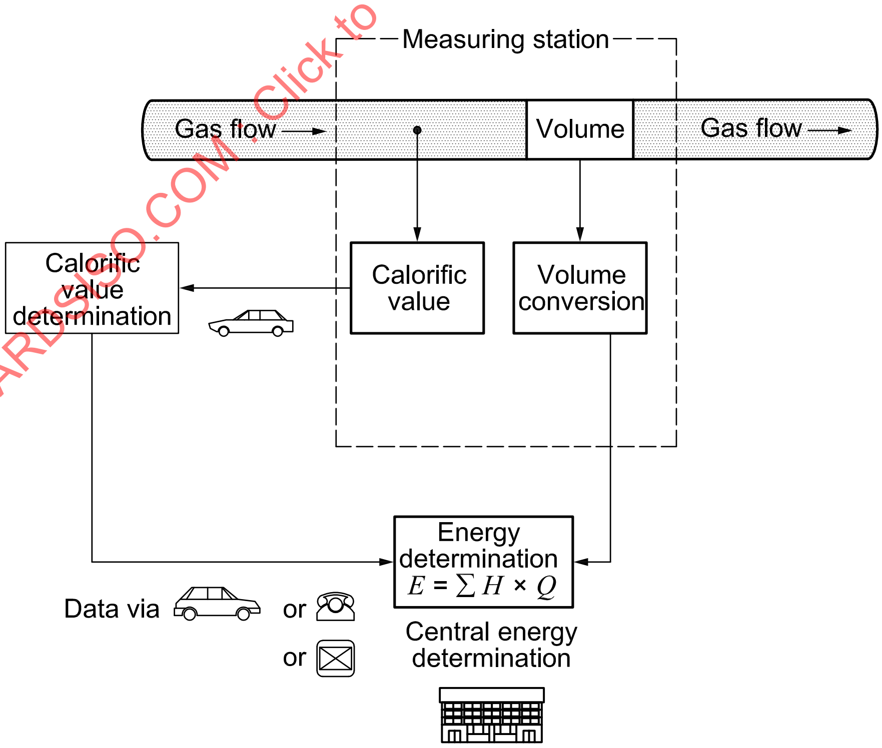


Figure 7 — Local offline calorific-value measurement

7.2.2.2 Measurement of volume or mass and calorific value at different stations

Whereas the gas volume is measured at every delivery point between contract parties, it can be too expensive to operate a calorific-value measurement device there, too. Thus, the most common method (especially in extensive supply systems) is to assign a representative calorific value (see Clause 9) to the volume. The calorific values assigned to those interfaces (volume-measuring points) are values measured elsewhere or a value formed from several representative measured values (see Figure 8). These values are the basis for energy determination. The kind of assignment is determined by the location of the input/output stations in the grid and the conditions of gas flow (see Clause 9).

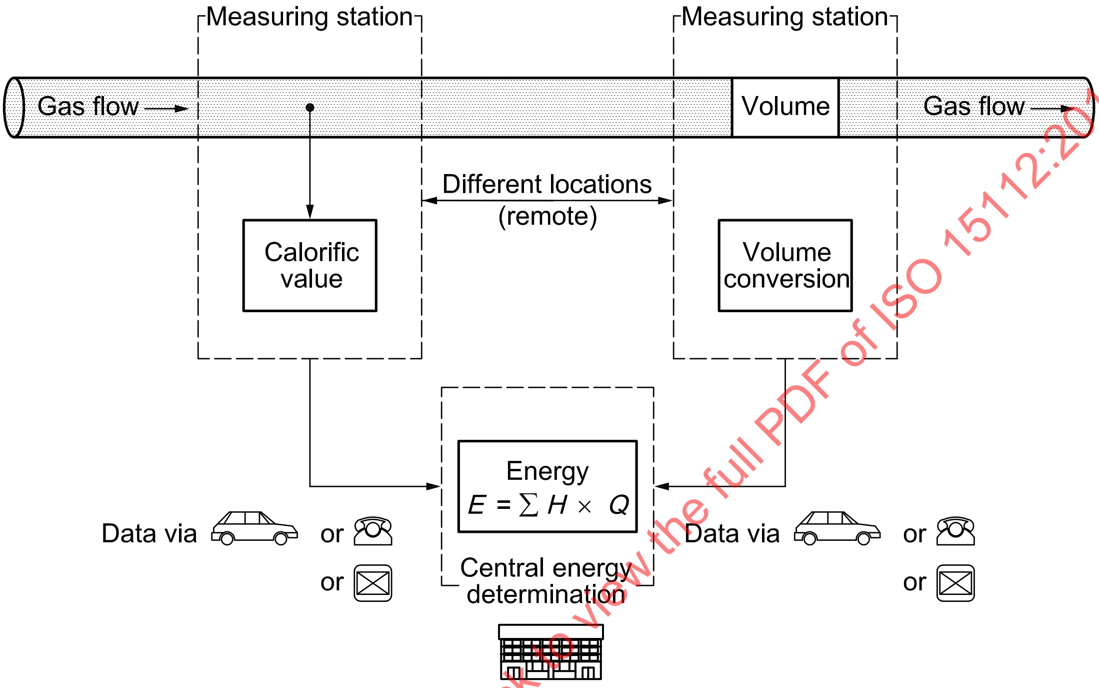


Figure 8 — Remote calorific value measurement (example)

8 Strategy and procedures

8.1 General

“Design” in the context of this International Standard encompasses the requirements of what information is necessary and how it should be obtained to fulfil the needs of the energy-determination strategy, taking into account the expected course of data.

Energy determination starts with an assessment of a reasonable energy-determination strategy, followed by a plausibility check of the measured data. The next steps are the assignment of the representative calorific value and the combination of the data (calculation procedures). Finally, a quality-control procedure is performed.

An energy-determination scheme, including “start” and “end” points, is shown in Figure 9.

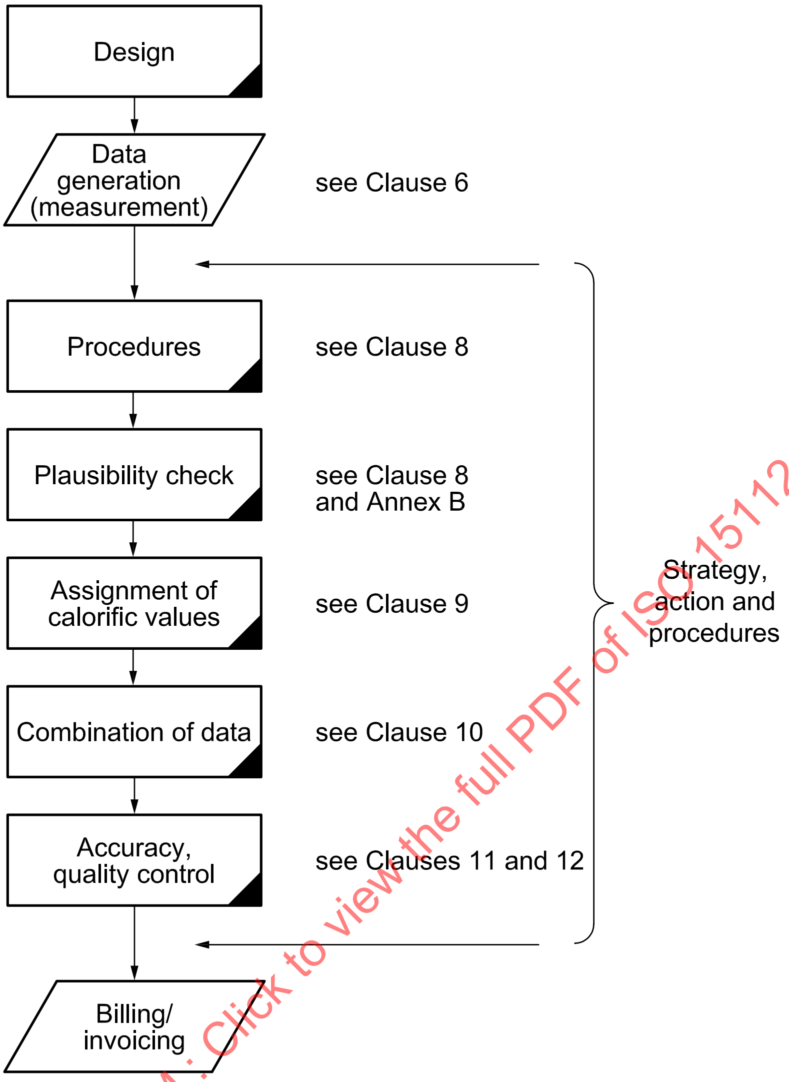


Figure 9 — Strategy for an indirect energy determination

Principally, elaborated strategy and the applicable methods and procedures for energy determination shall be applied without changes. They may be changed only if

— it can be assured that the accuracy of the results will be better or as a minimum not worse, or

— the methods or procedures are no longer applicable, due to the changed gas flow and/or gas quality conditions.

Additionally, due to significant changes with respect to the economics, it may be necessary to change the applicable methods/procedures.

Gas measurement systems are not the subject of this International Standard. However, data generated by new systems or modified devices can cause a better or worse quality of the data; this can lead to modifications of energy determination.

8.2 Strategies for energy determination

For an energy-determination period, it is necessary that a reasonable energy-determination strategy take account of

- the course of the calorific value (calorific value changes) with respect to the relevant supply situation, and
- the correctness of the measuring data (i.e. the raw data)

for a specified interface.

Taking into account the changes in gas quality at an interface is a key factor for the justification and accuracy of the energy determination, i.e. the traceable determination of the calorific value for the relevant interface.

This is important because even a non-corresponding energy-determination strategy at the interfaces can be disadvantageous for one partner and shall be avoided. This can happen, for example, by using a non-matching, i.e. non-representative, calorific value or other non-representative physical data (i.e. density, CO_2) at those interfaces where only the gas volume is measured, or by taking raw data without any critical check.

Generally, changes in gas quality depend on the gas supply situation at that interface, i.e. it is necessary to prove

a) whether gas from only one origin has passed the subsequent interfaces (see Figures 12, 13 and 15), or

b) whether gases from more than one origin have passed the subsequent interfaces (see Figures 14 and 15).

Supply situations according to Figures 14 and 15 very often result in reasonable changes in gas quality due to the delivery and take-off situations.

Thus, the changes of the daily or monthly averaged calorific values over one billing period (one month, respectively, one year) shall be carefully monitored to decide whether an energy determination period for billing purposes shall be divided into smaller periods.

Changes in gas quality within one day do not usually result in a further subdivision into hourly values. For examples, see Annex B.

8.2.1 Strategies for the single interfaces

8.2.1.1 General

Large quantities of gas generally pass interfaces 1 to 3 (see Figures 3 and 4). For interfaces 2 and 3, the relevant calorific value can be determined relatively easily by local measurement (see Figures 6 and 7), remote calorific value measurement (see Figure 8) and appropriate assignment methods or quality tracking (see 9.3.3). It is up to the contract partners and local authorities to agree upon the matching method.

At those points on the gas grid where a measurement of the calorific value and other important gas quality entities can usually not be performed for technical and/or economical reasons, a determination of these entities in an indirect way can sometimes be performed (see 9.2, 9.3.1, 9.3.2 or 9.3.3).

8.2.1.2 Interface 1

For the calculation of the volume under reference conditions, a volume conversion is either performed by

- p, T and Z, or
- ρ_n and ρ.

At that interface, the calorific value shall be measured online (see 6.3).

In the case of gas production from a single reservoir where the gas composition may be expected not to change over time, online measurement for the determination of the calorific value may not be necessary. In this case, the calorific value may also be calculated from the gas composition obtained from offline analysis of periodic samples. For an example, see Annex J. In all other cases, calorific measurement according to the rules that apply for interface 1 shall be followed.

The development over time of separate calorific values relative to the initial calorific value is assessed statistically. If the values exceed an agreed limit (for example 0,5 %, see Figure J.1) over time, the method shall be changed from offline measurement to online measurement.

The application of this method for calorific-value determination should take into account the fact that the delivery composition of the gas is strongly dependent on the type of gas treatment installation.

For the determination of the compression factor, Z, see 6.4.4.

8.2.1.3 Interface 2

The calculation of the volume under reference conditions is performed as described in 8.2.1.2.

The determination of the calorific value for energy-determination purposes is performed by measurement (see 6.3) or assignment (see Clause 9).

8.2.1.4 Interface 3

The determination of the values for energy determination is performed as described in 8.2.1.3. The user of this International Standard should take into account that methods and/or facilities at interface 3 to determine the calorific value, especially for the subsequent interfaces, can differ from country to country.

8.2.1.5 Interface 4

At interface 4 of the gas grid, a measurement of the calorific value and other important gas quality entities can usually not be performed for technical and/or economical reasons. For this interface, assignment methods (see Clause 9) are necessary.

Before the gas passes the measuring device, upstream a stable pressure of the gas shall be ensured by means of pressure control. The local distribution company (LDC) determines procedures to set the relevant temperature and pressure that can be used for energy-determination purposes, taking into account the ambient pressure. Due to the low pressure, the compression factor is not calculated and set to “1”.

For this interface, either a declared or assigned calorific value can be applied, using the upstream calorific value of interface 3.

If only reasonably small changes in gas quality can be expected (see Figure B.1), it is advisable to use only a declared calorific value for annual energy-determination periods. A declared calorific value is set by the LDC at a fixed value, taking into account the calorific values of the previous 12 months (see Figure B.1). During the energy-determination period, the LDC regularly checks the calorific values at (upstream) interface 3 from where the gas is feeding interfaces 4.

If the difference between the declared calorific value and the calorific value determined upstream at interface 3 is larger than the permitted difference (for example 1 %), for example when the calorific value has changed significantly (see Figures B.2 and B.3), these calorific values shall be assigned to the energy-determination periods. For example, in Figure B.2, the calorific value H_{S1} shall be assigned for energy-determination purposes for the time periods t_1 and t_2, and the calorific value H_{S2} for the time period t_3.

To ensure a reasonably accurate energy-determination process for those customers, a distinction shall be made between

- a gas grid separated from other gas qualities, and
- a gas grid (open grid) not separated from other gas qualities.

8.2.1.5.1 Gas grid separated from other gas qualities

If gases with different calorific values are kept separately in different gas grids, no mixing of these gases can occur and the calorific value measured or determined at interface 3 may be taken as the basis for energy determination at interfaces 4, as follows.

The average of the calorific value can be calculated either arithmetically or on an hourly volume- or quantity-weighted basis in the manner described in 10.2.

a) At first, at the end of every day or another interval within the energy determination period, the energy quantity of the gas passing interface 3 is calculated by averaging the measured/determined individual calorific values [see Equation (6)] and multiplying that averaged calorific value by the gas volume or quantity that had passed interface 3 during the same interval [see Equation (7)] in the following manner.

   - For this purpose, the individual calorific values within 1 h are averaged using Equation (6). ("hourly-based averaged calorific values").

   - These hourly-based averaged calorific values are used to calculate a daily averaged calorific value using Equation (6) or, for weighted averaging, Equation (8).

   - Finally, that daily averaged calorific value is multiplied by the gas volume or quantity that had passed interface 3 during the same day.

b) Secondly, at the end of the energy-determination period, the energy quantities of all intervals will be summed up and divided by the sum of all gas volumes/quantities of all intervals of that energy-determination period [see Equation (8)].

The resulting averaged calorific value can be applied for the calculation of the energy of any interface 4 on the grid. For further details, see 9.1. Practical examples are given in Annex F.

8.2.1.5.2 Gas grid not separated from other gas qualities

If end users at interface 4 are supplied via several interfaces 3, the calorific values measured/determined at all such interfaces 3 are relevant.

If the calorific values change over time at these interfaces, it is usually impossible to perform a calorific value measurement at each interface 4 due to economical reasons, even if, according to local conditions (i.e. complicated topology, low pressure), the supply situation is unclear. Mostly due to relatively small gas quantities at that interface, technical measures, such as sampling, calorific-value measurement, state reconstruction, etc., cannot usually be justified as a means of increasing the accuracy.

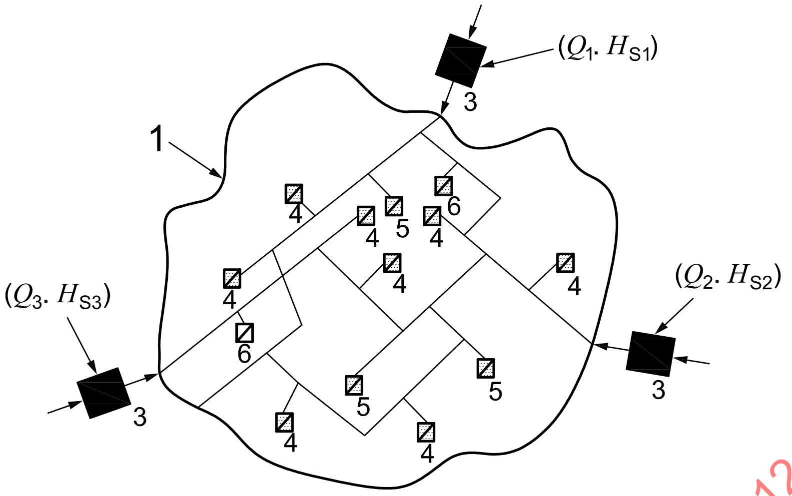
If different gas qualities are fed into a gas grid at several interfaces 3, the calorific values for the interfaces 4 are calculated by arithmetically averaged calorific values (see 9.3.1) or by the following procedure.

a) At first, the energy quantity for each interface 3 is calculated for the energy-determination period as described in 8.2.1.5.1.

b) The energy quantities of all interfaces 3 are then summed up and divided by the sum of all gas volumes or quantities of all interfaces 3 of that period to give the weighted-average grid calorific value for that period.

c) If none of the weighted-averaged calorific values of any interface 3 deviates by more than a permitted value from the weighted-averaged grid calorific value, then the weighted-averaged grid calorific value may be applied for the calculation of the energy of every interface 4.

A practical example is given in Figure 10.



Key

1 changing area

Figure 10 — Determination of a weighted-average calorific value (example)

EXAMPLE A charging area, where the energy determination is being performed, is supplied at the entry-point interfaces 3 by the gas quantities Q_1, Q_2 and Q_3 with the corresponding calorific values H_{S1}, H_{S2} and H_{S3}. These calorific values have been either measured at the entry points or determined upstream at interfaces 1 or 2 and assigned to these interfaces 3 as described in Clause 9. Then the averaged calorific value H for energy-determination purposes in the charging area is calculated as described at the above-mentioned points 8.2.1.5.1 a) and b).

For interfaces 5 and 6, this averaged calorific value can also be taken for energy-determination purposes or measured individually at these interfaces. In the latter case, the energy-determination procedure for all other interfaces in the charging area shall take account of the energy quantities determined individually via local calorific value measurement at interfaces 5 and/or 6.

If the deviation exceeds the permitted limit, the national authorities shall be informed about the measure of deviation and the procedure applied. The information is not necessary if, in extraordinarily rare cases, short-term (maximum one week) deviations occur, for example caused by measures to ensure the supply of gas.

If a reasonably accurate energy-determination process can be assured (see 8.2.1.5), arithmetic averaging of the calorific values may be considered. If the difference of the weighted averaged calorific value at interface 3 and the weighted averaged grid calorific value in the charging area is higher or lower than permitted due to strongly changing gas qualities at interfaces 3, the following additional measures inside the charging area can be taken. These measures are necessary to determine the representative calorific value for single parts of the pipeline system as representative as possible, for example, by the use of sampling techniques that take into account the quantities Q_1, Q_2 and Q_3 and the measured or calculated take-off structures of subsequent interfaces 4 to 6. In these cases, different average calorific values can be calculated for the various parts of the energy-determination system using the calorific values at the entry-point interfaces and the calorific values determined by sampling methods. For further details, see 9.2.

8.2.1.6 Interface 5

For industrial customers, i.e. interface 5, the relevant calorific value is determined either upstream by the gas transporter or by the local distribution company. Due to the large quantities and for economical reasons, the relevant calorific value for charging purposes is very often also determined at this interface. According to the gas quantities and pressures, energy determination at interface 5 is performed as it is at interfaces 1 to 4 (see 8.2.1.5.2).

8.2.1.7 Interface 6

The requirements for this interface are similar to those for interface 4. For details, see 8.2.1.5.2.

8.3 Plausibility checks

The first step for energy determination is the critical check of the plausibility of the measured, transmitted or recorded data. Non-plausible data can be caused for example by

- malfunction of a measuring device,
- external impacts, such as electromagnetic fields on communication lines,
- breakdown of recording devices, etc.

Other reasons for non-plausible data shall be carefully checked.

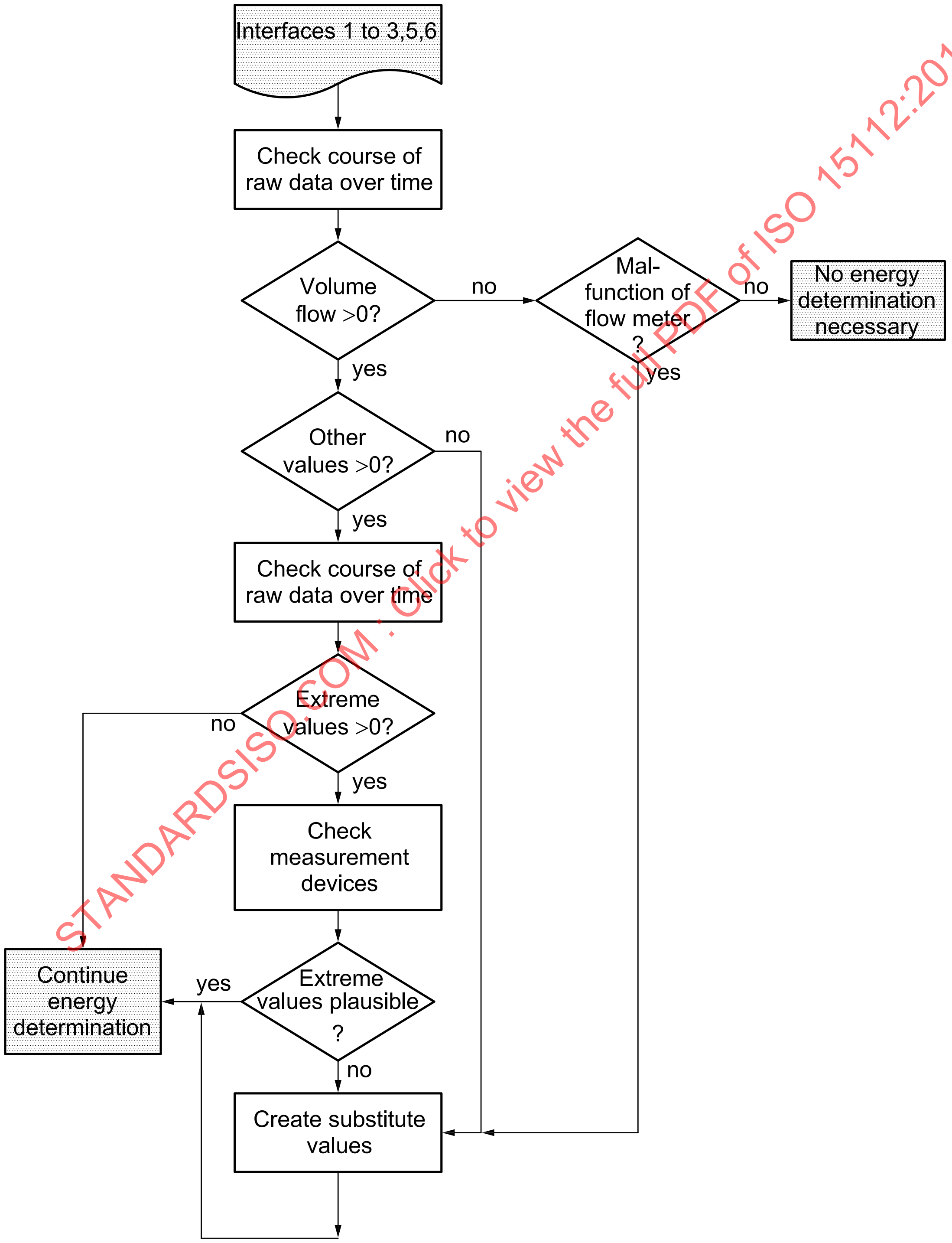


Figure 11 — Data plausibility check

The functional diagram in Figure 11 shows how to perform a plausibility check in a formal way. If the volume flow equals “0”, it should be checked whether or not it is true. If there was a flow and the data are “0”, a problem has obviously occurred, such as a malfunction of the meter or associated devices such as signal transmitters, electronic devices, data storage devices or others. Obviously false data shall not be used. For false or missing data, suitable substitute values (see 12.4) shall be determined.

The box “other values” means entities as pressure, p, temperature, T, density or others. “Extreme values” means values shown to be at the end of the scale.

A practical example is given in Annex H.

9 Assignment methods

9.1 Fixed assignment

A fixed assignment of a calorific value within a charging area for energy-determination periods can generally be performed in simple, separated grids if the following conditions are met.

— The direction of the gas flow between the calorific value and the volume-measuring points is constant.

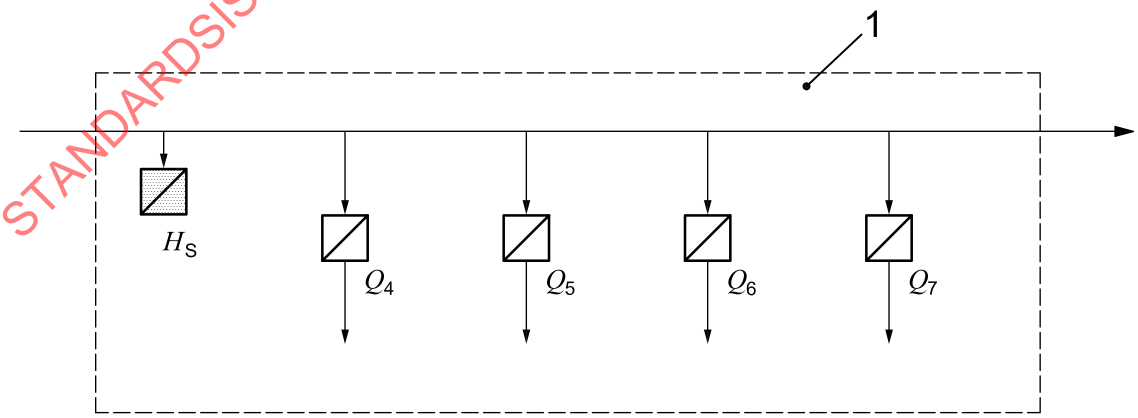
— The variation of the gas quality and the transit time of the gas between calorific value and quantity-measuring points are reasonably small (see 10.4 and Figure B.1) in that energy-determination period. Clause 11 can be used to check if the required accuracy of the energy determination can be met.

Generally, the methods described in 9.1.1 and 9.1.2 are possible.

9.1.1 Fixed assignment of a measured calorific value

The calorific value is measured at a calorific-value-measuring station. The data show that the variation of the gas quality is very small (see Figure B.1). Thus, it is justified to assign the mean of the previously measured calorific value as a fixed value to all subsequent interfaces. The assignment from a single calorific-value-determination station can be demonstrated as follows.

Figure 12 illustrates a single source of gas, whose calorific value, H_S, is determined at the entry point to the pipeline that is operated by a gas transporter/regional distributor and that feeds a number of interfaces at the pipeline. The calorific value assigned to all the interfaces is that determined at the entry point and is not modified to reflect the different times of transit of the gas to different interfaces.



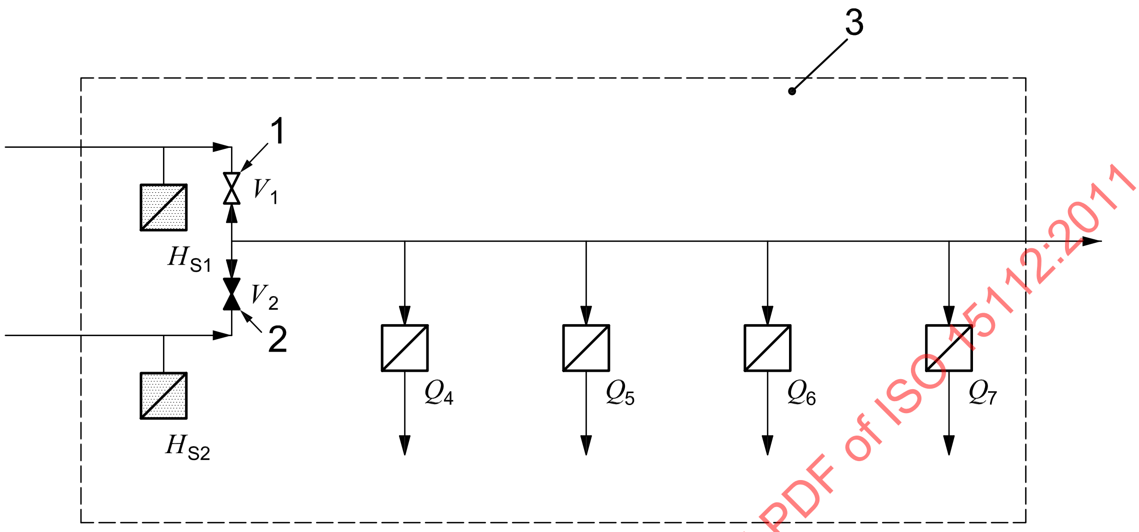
Key

H_S, Q_4, Q_5, Q_6 and Q_7	interfaces
1	energy-determination grid

Figure 12 — Example of a fixed assignment for one gas quality — Unidirectional gas flow

The assignment from two or more calorific-value-determination stations can be demonstrated as follows.

Figure 13 illustrates a system in which a gas transporter has the possibility of two different gases entering a pipeline. The two calorific values, H_{S1} and H_{S2}, one for each of the two gases, are determined at a point upstream of the entry (entry point) to the pipeline and there is no calorific-value measurement downstream of the entry point.



Key

H_{S1}, H_{S2}, Q_4, Q_5, Q_6 and Q_7	interfaces
1	valve 1
2	valve 2
3	energy-determination grid

Figure 13 — Example of a fixed assignment for two measured gas qualities — Unidirectional gas flow

The gas transporter decides to use a fixed assignment from one or the other of the calorific-value-determination points on the basis that

- a constant supply can be assured at all times from one source,
- the gas supply to the pipeline with the different gas qualities H_{S1} and H_{S2}, resulting in a gas mixture with a calorific value different from H_{S1} and H_{S2}, never happens (both valves are never open at the same time),
- the supply periods with each of the different gas qualities are recorded, and
- for assignment purposes, the calorific value, either H_{S1} or H_{S2}, is used for subsequent interfaces corresponding to the same supply period.

9.1.2 Fixed assignment of a declared calorific value

The calorific value is assumed to be reasonably constant over time within an energy-determination period. The calorific value is measured for checking purposes at a calorific-value-measuring station. The data acquired confirm that the variation of the gas quality is very small (see Figure B.1). Thus, it is justified to declare a calorific value and assign that value to all subsequent interfaces.

EXAMPLE A local distribution company (LDC) has a gas grid supplying various customers, as domestic, commercial and small industrial consumers. There are a couple of interface entry points to a gas grid that are supplied with gas from a single pipeline. The calorific value of the gas flowing through the pipeline shows only small variations, except at times of peak demand during the winter when the calorific value can rise by up to 1 % in relation to the average calorific value.

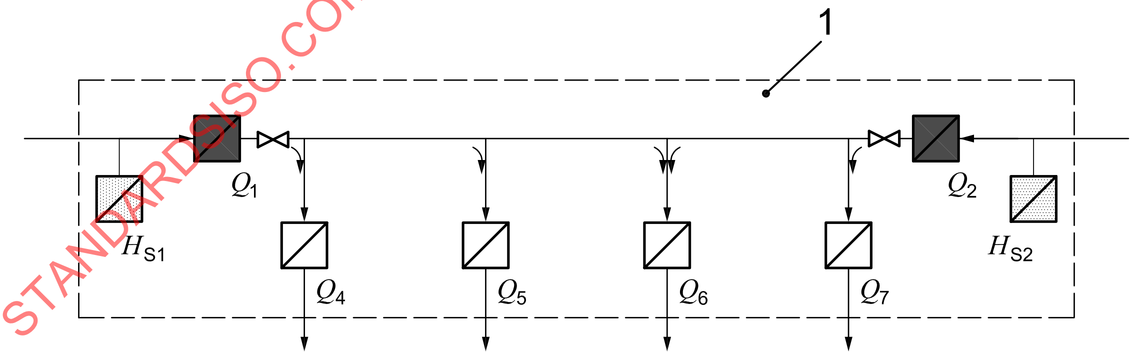
The LDC decides to use a fixed assignment of a declared calorific value for all interfaces on its gas grid; the calorific value is declared for a period of time on the basis that

- the determined calorific value of the gas supplied to consumers is, on average, equal to, or higher than, the declared calorific value (to the nearest 0,1 MJ/m^3),
- the average calorific value of the gas supplied to consumers is calculated by averaging, for each day in the declared period, the lowest calorific value of gas,
- the calorific values of all gases entering the grid are determined on a daily basis, and
- if, for any period, the determined calorific value falls below the declared figure, then the LDC will revise the declared value for the following period such that, over the two periods, the determined value is equal to, or higher than, the average declared value.

9.2 Variable assignment

Especially in open gas grids, gas qualities at the interfaces can vary significantly with time (see Figure B.3). In this case, the requirements for a fixed assignment are no longer applicable and it is necessary to adapt the assignment/calculation method that is suitable for conditions that change with time. The choice of a suitable assignment method changes according to changes in the gas quantities at the input stations, as well as changes in the take-off structures at subsequent interfaces. Thus, careful procedures for variable assignment of the calorific values shall be undertaken. There are two different situations, which shall be generally distinguished; they are described in 9.2.1 and 9.2.2.

9.2.1 Input at two or more different stations with zero floating point



Key

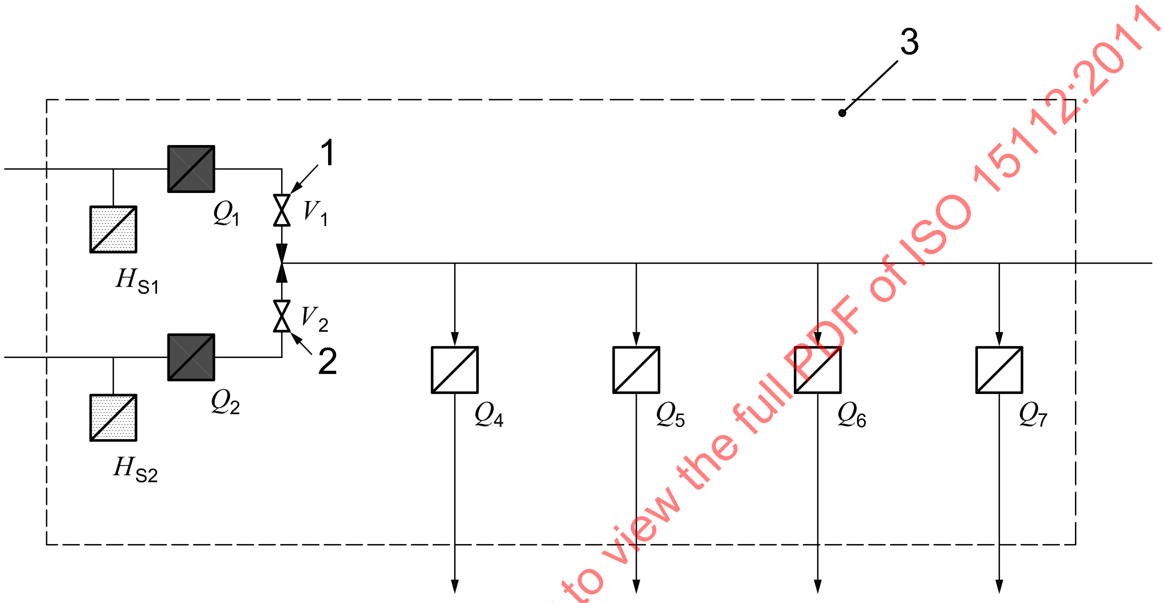
H_{S1}, H_{S2}, Q_1, Q_2, Q_4, Q_5, Q_6 and Q_7	interfaces
1	energy-determination grid

Figure 14 — Variable assignment — Example for two measured gas qualities and bidirectional gas flows

EXAMPLE For an energy-determination period (see Figure B.3), as shown in Figure 14, different gas quantities and qualities pass the interfaces 1 and 2 (input stations). The defined zero floating point can be located between two interfaces (for example, between two neighbouring interfaces or between an input station and a neighbouring interface). According to the take-off structures at the interfaces 4 to 7, gas with the calorific value H_{S1} can supply interfaces 4 and 5, whereas gas with the calorific value H_{S2} can supply interface 7. A mixture of gas from interfaces 1 and 2 can pass interface 6. Thus, the calorific value H_{S1} can be assigned to interfaces 4 and 5 and the calorific value H_{S2} can be assigned to interface 7. For interface 6, the representative calorific value can be either measured at that interface or determined taking into account the partial gas quantities from Q_1 at interface 1 and Q_2 at interface 2 and the applicable calorific values H_{S1} and H_{S2} using flow or arithmetic weighted averaging (see 10.2.2). The zero flow in the main pipeline can be situated at or between the interfaces 4 to 7.

For the period during which the defined zero floating point has a fixed position within the grid, calorific values can be assigned to each interface on the basis of the gas flows from the input stations to the respective interfaces.

9.2.2 Input at two or more different stations with comingled gas flows



Key

H_{S1}, H_{S2}, Q_1, Q_2, Q_4, Q_5, Q_6 and Q_7	interfaces
1	valve 1
2	valve 2
3	energy-determination grid

Figure 15 — Variable assignment — Example for two measured gas qualities and unidirectional gas flow

EXAMPLE During an energy-determination period, the quantity Q_1 at interface 1 with the calorific value H_{S1} and the quantity Q_2 at interface 2 with the calorific value H_{S2} are measured. The two calorific values are always different from each other and can also change during the energy-determination period. Due to this situation, for the calorific value assignment to interfaces 4 to 7, a pattern of the resulting calorific value for each interface 4 to 7 similar to that in Figure B.3, for example, can result at interface 4.

If the calorific-value-measuring stations H_{S1} and H_{S2} are far away from the interfaces Q_4 to Q_7, the run time of the gas from these measuring stations H_{S1} and H_{S2} to the interfaces Q_4 to Q_7 shall additionally be taken into account; this may be hours or days. A calculation is performed on the basis of the quantities Q_4 to Q_7, the respective pressures and the pipeline sectional area including the line pack.

A quantity-weighted averaged calorific value shall be calculated at the mixing points behind valve 1 and valve 2 for the gas quantities Q_4 to Q_7 supplied to the respective interfaces 4 to 7 for the energy-determination period, taking into account the run times from the calorific-value-measuring stations for H_{S1} and H_{S2} to the mixing point.

9.3 Determination of the representative calorific value

The accuracy of the determined representative calorific value depends on the completeness and accuracy of the data and the topology of the gas grid. For determining the representative calorific value at the mixing point, the calorific value is calculated using the gas quantities and qualities. To get the representative calorific value, the run time from the input stations to the mixing point, as well as the run time to the subsequent interfaces, may be taken into account. For the determination of the representative calorific value for the energy-determination period at each interface, in all cases except fixed assignment, the methods given in 9.3.1, 9.3.2 and 9.3.3 may be used.

9.3.1 Arithmetically averaged calorific value

For an entry-point interface, an arithmetically averaged calorific value is calculated for the energy-determination period by dividing the sum of periodic single calorific-value measurements at the entry point by the number of measurements of the calorific value (see 10.2.1).

9.3.2 Quantity-weighted average calorific value

For an entry-point interface, a quantity-weighted average calorific value is calculated at this interface for the subsequent interfaces (see 10.2.2) for the energy-determination period.

9.3.3 Quality tracking

This special assignment method involves the calculation of gas qualities at any place in a pipeline or a grid by means of a grid simulation or a state reconstruction based on gas qualities measured at all supplying points on the pipeline(s).

The objective of gas-quality tracking is to yield information about the gas quality for those places of a pipeline or a grid where no gas-quality measurement is installed.

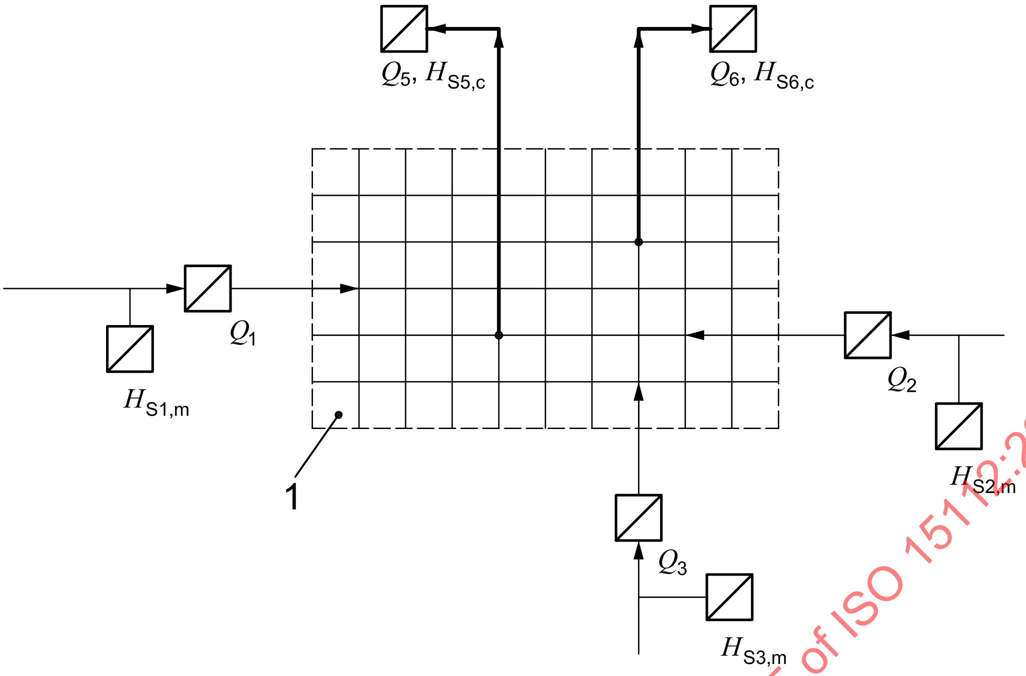
The accuracy of the calculated gas qualities depends on the completeness and accuracy of the topology, the measured data and the performance of the mathematical model.

9.3.3.1 State reconstruction of calorific values

State reconstruction involves an offline calculation of the set of all relevant pressures and flow rates in a real pipeline or grid on the basis of the complete topology, the checked measured values of the flow rates at all supplying and take-off points and of the pressures and temperatures, and possibly additional flow measurements, at various points on the pipeline(s) using an appropriate dynamic mathematical model.

The objective of a state reconstruction is to yield accurate information about the real flow states of a pipeline or grid. Therefore, the results of a state-reconstruction-based gas-quality system may be used for billing purposes. In this case, the operation of such gas-quality tracking systems shall be monitored by additional quality reference measurements at appropriate places on the pipelines.

In Figure 16, a grid with a lot of receiving stations (interfaces 5 and 6 are two examples) without calorific value measurement is schematically shown. H_{S1} to H_{S3} are the measured calorific values of the gas quantities Q_1 to Q_3, respectively, from different origins, and H_{S5} and H_{S6} are the calculated calorific values at the receiving stations with the gas quantities Q_5 and Q_6, respectively.



Key

Q_1, Q_2, Q_3, Q_5 and Q_6	interfaces
1	grid model

Figure 16 — Example of a reconstruction-based gas-quality tracking scheme

9.3.3.2 Grid simulation

In grid simulation, the calorific values are also calculated for any point on a pipeline or grid, but because the input data (topology, calorific values, flows, pressures and temperatures) are only unchecked online data or even assumed values, the results are normally inaccurate and, therefore, inappropriate to be used for billing purposes.

In order to avoid confusion, the term "grid simulation" should not be used as a synonym for "state reconstruction".

10 Calculation of energy quantities

10.1 General equations for energy

In accordance with Figure 2, energy determination of a gas flow is based on entities changing in time:

Current flow	$q = q(t)$
Current calorific value	$H = H(t)$

For the determination of the energy flow, $e(t)$, the basic differential equation is given in Equation (1):

$$e(t) = H(t) \cdot q(t) \quad (1)$$

The quantity of energy, $E(t_j)$ flowing within a period of time t_0 to t_j (for example within an energy-determination period; see Figures B.1 to B.3) is calculated by integration of Equation (1) from time t_0 to time t_j and giving $E(t_j)$ as given in Equation (2):

$$E(t_j) = \int_{t_0}^{t_j} e(t)\mathrm{d}t = \int_{t_0}^{t_j} H(t) \cdot q(t)\mathrm{d}t \tag{2}$$

NOTE For example, for a gas flow measured over 24 h or one day $E(t_j)$ becomes $E(24)$ that corresponds the quantity of energy of that period.

The shortest period of time for energy determination for billing purposes is 1 h or multiples thereof (i.e. days, weeks, months, one year).

For the energy determination during 1 h, the following two procedures are possible (see also 7.2.2.1 and 7.2.2.2):

— multiplication of the calculated volume under reference conditions with the averaged calculated calorific value of the same hour;

— *in situ* energy calculation in the volume-conversion device using the actual measured entities for the calculation of energy based on the calculation of Q_r and H_r, followed by summing these single energy quantities over 1 h.

The relevant hourly values can subsequently be added to derive daily, monthly or annual quantities.

Calculation equations:

A small time interval, Δt, is set such that the calorific value, $H(t)$, may be assumed to be a constant entity, H_const. In practice, H_const matches the result of measuring devices that periodically determine and yield the last measured value between measuring cycles.

To simplify the process, the period t_0 to t_j is subdivided into j time intervals in order to meet the assumption, as given in Equation (3):

$$E(t_j) = H_{\mathrm{const},1} \times \int_{t_0}^{t_1} q(t)\mathrm{d}t + H_{\mathrm{const},2} \times \int_{t_1}^{t_2} q(t)\mathrm{d}t + \ldots + H_{\mathrm{const},j} \times \int_{t_{j-1}}^{t_j} q(t)\mathrm{d}t \tag{3}$$

The integrals in Equation (3) correspond to the transported quantities, Q, of gas in the respective time intervals, Δt; they can be calculated by integration of the actual gas flow over the time, t, as given in Equation (4):

$$Q(t) = \int q(t)\mathrm{d}t \tag{4}$$

In practice, however, measuring systems yield the quantity, Q, directly as the result of a measurement.

Thus, Equation (4) can be rewritten as Equation (5):

$$E\left(t_j\right) = \sum_{m=1}^{j} E_m = \left(H_{\mathrm{const},1} \times Q_1\right) + \left(H_{\mathrm{const},2} \times Q_2\right) + \ldots + \left(H_{\mathrm{const},j} \times Q_j\right) = \sum_{m=1}^{j} \left(H_{\mathrm{const},m} \times Q_m\right) \tag{5}$$

Equation (5) can be used for any energy-determination period, i.e. from 1 h to days or months.

The monthly average for calculating thermal energy can, for example, be computed from daily values.

For the practical application of incremental energy determination, see Annex D.

10.2 Calculation of averaged values — Calculation from average calorific values and cumulative volumes

When the calorific value is constant during the time period t_0 to t_n (see Figure B.1), no special calculation is required; if the calorific value changes during this period of time, the procedures for calculation of the appropriate calorific value described in 10.2.1 and 10.2.2 are used (see Figures B.2 and B.3).

10.2.1 Arithmetic average of the calorific value

In practical use, the calorific value is often measured at a representative point of the pipeline grid and allocated to volume-measuring stations located at other points. Thus, the arithmetic average of the calorific value, H_{arith}, is derived from n single measurements, as given in Equation (6):

$$H_{\text{arith}} = \sum_{m=1}^{j} H_m / j \tag{6}$$

Equation (5) can be simplified, if the single factors, $H_{\text{const},m}$, are similar to the arithmetic average value, H_{arith}, as given in Equation (7):

$$E = H_{\text{arith}} \times Q \tag{7}$$

10.2.2 Quantity-weighted average of the calorific value

If the energy of the gas quantity transported from time t_0 to t_n is set in relationship to the gas quantity, $Q(t_n)$, that was transported in the same time period, the so-called “quantity-weighted average of the calorific value” is given by Equation (8), taking into account Equation (5):

$$H(t_j) = E(t_j) / Q(t_j) = \sum_{m=1}^{j} H_{\text{const},m} \times Q_m / \sum_{m=1}^{j} Q_m \tag{8}$$

Each of the j single calorific values, $H_{\text{const},m}$, is weighted by the respective quantity Q_m.

For practical examples, see Annex F.

10.3 Volume and volume-to-mass conversions

Where gas-quality data are required for conversion purposes at the interfaces, it is necessary that those data shall relate to the gas flowing to those interfaces, for example by having been measured at the appropriate calorific-value-measuring station. If the calorific value is expressed in volume units and the quantity of gas is measured in mass units, then the calorific value shall be converted from volume units to mass units.

See Annex C for a general description. For practical examples based on physical properties, see Clause E.1; for practical examples based on the gas composition, see Clause E.2.

10.4 Energy determination on the basis of declared calorific values

To enable a practical, easy energy determination mainly at interface 4, but also applicable to interfaces 5 and 6 (see Figures 3 and 4), a calorific value may be declared within an energy-determination period for a charging area with a set of different interfaces. Prior to the energy-determination procedure, the declared calorific value shall be determined by means of the weighted-average calorific value. For example, if the energy-determination period is one year, the calorific value is determined for each month as an arithmetic or a weighted mean. At the beginning of the month in which energy determination is performed, the weighted annual mean is calculated using the last 12 months' means and taking into account the monthly take-off quantities for the relevant customer/customers.

For longer energy-determination periods, that month in which energy determination is performed shall not be taken into account for calculating the mean value.

A declared calorific value is set by the LDC in the case of an annual energy-determination procedure. The difference between the declared calorific value and the actual mean should be assessed annually. If the difference is more than 1 %, the actual mean should be taken. It is important that there be, over a long time period, no significant bias between the declared and calculated averaged calorific values.

A practical example is given in Annex B.

11 Accuracy on calculated energy

11.1 Accuracy

11.1.1 The accuracy on the quantity of energy determined as passing a particular interface is a combination of

- uncertainties, and
- biases.

11.1.2 Uncertainties can have two sources:

- uncertainty of the measurements of the gas quantity and calorific values made for the determination of energy;
- variability of the parameter being measured (of particular importance when the numerical value of that parameter used in the determination of energy is obtained by some process from measured values).

Uncertainties can be quantified but not eliminated.

11.1.3 Bias results from systematic differences between the actual quantity and calorific value used in the calculation of energy at a gas-measuring station and the true values for those parameters.

A possible bias in the determined energy has a number of sources, such as

- an error in a calibration factor that affects subsequent measurements,
- use of fixed factors, for example in the conversion of measured gas volumes to the corresponding volume under reference conditions, or
- a calorific value attributed to an interface having only gas-volume measurement that may be unrepresentative of the gas passing that interface.

General information on the calculation of uncertainty and identification of bias on the determined quantity of energy is given in 11.2 and 11.3. A graphical example to show the principal difference between uncorrected measurements, biases and the final result of a measurement (for example a corrected calorific value) by means of a graph, based on ISO/IEC Guide 98-3 (GUM), is given in Annex I.

11.2 Calculation of uncertainty

The relative uncertainty, $u(E)$, of the energy is calculated from Equation (9), which is derived from the general equation for the determination of energy, Equation (10):

$$u(E) = \left[u^2(H) + u^2(Q)\right]^{1/2} \tag{9}$$

where

$u(H)$ is the relative uncertainty of the calorific value;

$u(Q)$ is the relative uncertainty of the quantity of gas.

When calculating uncertainties in energy, it is necessary to take into account the uncertainties of all known influencing factors [see ISO/IEC Guide 98-3 (GUM)].

The total uncertainty of the calculated energy is also affected by the manner in which integration is carried out with respect to the period of time over which the energy calculation is made. If at a gas-measuring station both volume and calorific value are measured and over very short intervals of time the energy is calculated and each of these individual energy sums for the total period are added together, then the integration has a relatively small effect on the total uncertainty. At the other extreme, where the total gas volume delivered over a period of months is multiplied by an average calorific value for that period to obtain the energy for the period, then the effect of the integration on the total uncertainty can be significant, particularly when the rate of gas usage and the actual calorific value vary over the time period. When applying a calorific-value assignment method, the effect of the time delay on the uncertainty shall be taken into account. The practical calculations of uncertainty [see ISO 12213 (all parts) for the calculation of the uncertainty of Z] depend upon the way in which the quantity of energy passing an interface is calculated (see Clause 8).

NOTE The uncertainties of the flow rate, p, T and Z, can be determined as given in the flow-measurement standards and ISO 12213 (all parts). As a first approximation, the relative uncertainty for an individual energy calculation can be regarded as equal to the relative uncertainty of the energy calculated over longer periods of time (even over a billing period) obtained by integrating the small portions of energy. This approximation is only applicable when

a) the relative uncertainty of the measured calorific value is constant over the range of measured calorific values, and

b) the relative uncertainty of the measured quantity is constant over the measuring range of the flow meter. In practice, this assumption is valid only over a part of a flow meter's range. For example, for some orifice plate metering systems, the uncertainty is essentially constant over 30 % to 100 % of Q_{max}. In some cases, it can be acceptable to use the maximum relative uncertainty for the range of flow rates that are experienced by the flow meter.

The energy, E, is calculated from Equation (10), the general form of Equation (7):

$$E = H \times Q \tag{10}$$

where H is the average or assigned calorific value for the period.

The uncertainty $u(E)$ is calculated from Equation (9), where $u^2(H)$ is the uncertainty of the average or assigned calorific value.

The uncertainty of the average or assigned calorific value contains three elements:

- uncertainty of measurement;
- uncertainty due to variation of the calorific value of the gas over the averaging period;
- time delay.

11.3 Bias

11.3.1 Wherever possible, a bias (see Annex I) should be identified and eliminated.

Where both the calorific value and volume and/or mass are measured at an interface, bias in the determined energy can arise from potential sources, such as

- calibration errors, or
- use of fixed factors instead of online data, for example, in the conversion of volume from operating to recommended standard reference conditions.

Identification of the source of bias should be achieved through a comparison of data (see 9.2.2), for example a determination of the composition and calorific value of a certified test gas to verify the properties of a calibration gas. In some instances, it can be possible to compare the outputs from measuring systems that are in series, for example, two different measuring systems at the same interface operated by different upstream and downstream measuring partners.

The potential for bias in the determined energy is increased when calorific values are assigned to an interface and/or where simple meters are in use. It can be possible to identify circumstances in which biases are introduced but the options to quantify and eliminate a bias can be limited to procedural changes.

11.3.2 Bias can result from the manner in which the gas volume measured by the meter is converted to an equivalent volume expressed under standard reference conditions. The possibility of bias is high for the relatively simple meters used at interface 4 for domestic consumers, such as

- where the conversion of the measured gas volume at operating temperature to the equivalent volume at standard temperature involves an assumed, fixed value for the operating temperature of the meter; in such cases where the operating temperature is higher than the assumed temperature, the gas volume calculated at the standard temperature is erroneously high, and vice versa, or

- where the conversion of the measured gas volume at operating pressure to the equivalent volume at standard pressure involves the use of a fixed average pressure, for example derived from an average altitude to compensate for atmospheric-pressure variation with altitude; in such cases where the altitude of the interface is higher than the fixed altitude, the gas volume calculated at the standard pressure is too high and vice versa.

11.3.3 Bias can also result from the fact that the calorific value assigned to the interface is not sufficiently representative of the gas passing the interface caused by, for example:

- use of a time-averaged calorific value at an interface where the flow rate of gas varies significantly, possibly even falling to zero, with time;

- use of a flow-weighted average calorific value for a network in which the majority of interfaces are systematically supplied from sources having calorific values different to the flow-weighted average value;

- use of a declared calorific value which, for reasons of regulation, is required to be lower than the calorific value of the gas passing any interface in a network.

12 Quality control and quality assurance

12.1 General

The energy-determination system shall be monitored to ensure its proper functioning and to keep it at its intended level of accuracy and integrity, e.g. by redundant systems. This covers all maintenance, verification and calibration activities pertaining to the system during its lifetime and can be accomplished by maintaining a record of the system performance. Data handling and data transmission shall be performed using safe and secure procedures.

If matching data for a comparison over time are given, the data shall be assessed to recognize possible bias and to evaluate it. This step can usually be performed only if a suitably large quantity of data has been collected, for example after one year. Therefore, the data generated in accordance with Clause 10 are directly used for billing purposes.

Quality control should be embedded in the existing (maintenance) organization of the user.

12.2 Check of the course of the measuring data

To avoid permanent disadvantages of partners causing cross-subsidies of other customers, bias should be avoided at all interfaces. The detection of biases can be performed by comparison on the basis of statistical methods using graphical tools and/or calculation tools, for example, the CUSUM method (see ISO/TR 7871).

When using statistical methods on the basis of calculation tools for the detection of bias, the user should take into account that the application of these methods is usually reasonable only for interfaces with large quantities of gas, where extended data acquisition and data analysis, including historical data, can be submitted.

Generally, the following possibilities for performing a data comparison are available:

- calibration standard ⇔ calibration standard;
- calibration means ⇔ measuring device;
- measured values ⇔ calculated values;
- measuring device ⇔ measuring device;
- input station ⇔ sum of output stations.

In general, the detection of a bias can reasonably be accomplished only when taking into account a suitably long time period.

For calorimeters, such an interval may be within two calibration periods, for example one month. Usually a comparison of volume-measuring stations is reasonable only after one year, taking into account random summer/winter effects. Where biases (systematic errors) are identified, action shall be taken to quantify and eliminate the bias; in the meantime, suitable substitute values or correction factors shall be used.

12.3 Traceability

Given the physical implications of custody transfer of natural gas, accuracy of measurement of the delivered energy is of fundamental importance. Inaccuracy in the sense of bias or systematic error favours one party at the expense of the other. Random errors have a neutral effect.

Most measurement instruments operate on a comparative technique, and the measurement accuracy is fundamentally influenced by the accuracy of the calibration standard used. Hence the interest in reference materials and in traceability. Traceability is the property of a result of a measurement whereby it can be related, with stated uncertainty, to stated references, usually national or International Standards, through an unbroken chain of comparisons.

12.4 Substitute values

Energy determination shall be ensured at all times as long as energy is transmitted via an interface, even if the measuring instruments have partly or completely ceased to function.

If a measuring instrument has failed, substitute values are required until the proper function of the measuring instruments is restored. They shall be obtained on the basis of the most plausible available values and may be derived from measuring instruments, auxiliary equipment and/or computational models for quantitative estimation.

Substitute values and their origin shall be made known and explained to the contracting parties directly affected by the malfunctioning instrument. They require, in each case, the approval of the parties directly affected (generally the contracting parties). Substitute values shall be clearly distinguished from the other values.

The contracting parties directly concerned shall agree on the general procedures to obtain substitute values within a reasonable amount of time before energy transmission. Such procedures may involve

- upstream and downstream measuring instruments,
- linear regression,
- interpolation of the last plausible value before malfunction to the first plausible value after malfunction,
- hourly, daily, weekly, monthly or annual comparisons with equivalent past periods,
- comparison of output or plant efficiency in the case of industrial customers,
- comparison based on samples,
- comparison of flow conditions in multi-stream measuring systems with constant flow resistance,
- calculations according to physical laws of flow, etc.

Examples of such procedures are given in Annex G.

Annex A
(informative)

Main instruments and energy-determination techniques

Table A.1

Country	Interface(s) at which the following volume measurement techniques take place							
	Diaphragm	**Rotary displacement**	**Vortex**	**Turbine**	**Orifice**	**Ultrasonic**	**Other**	**Backup of volume metering**
Belgium	—	3,5,6	—	1,2,3,5,6	—	—	—	—
China	4,6	4,5,6	3,5,6	2,3,5,6	1,2,3,5,6	1,2,3,5	—	—
Germany	4,6	3,4,5,6	2,3	1,2,3,5,6	1,2	2	—	1,2,3,5
France	4,6	3,5,6	—	1,2,3,5,6	1,2	—	—	1,2
United Kingdom	4,6	5	—	1,5	1	4,5,6	—	1,5
Italy	4,6	3,5	—	3,5	1,3,5	—	—	1,3,5
Netherlands	4,6	3,5,6	—	1,2,3,5,6	1	1,2	—	1,2,3,5
Austria	—	—	—	1,2	1,2	—	—	1,2
Russian Federation	1,3,5,6	—	—	1,3,5	1,2,3,5	—	—	3,4
Hungary	4,5,6	3,5,6	—	3,5,6	1,3,5	—	—	1,3
USA	4,5,6	1,2,3,4,5,6	3,5	1,2,3,5,6	1,2,3,5	2,3,5	5[a]	1,2,3,5

[a] Venture nozzle and mass.

Table A.2

Country	Interface(s) at which the following activities take place											
	Measurement of		Data storage		Measurement of density at		Compressibility factor calculation	Volume conversion	Calorific measurement	Calorific value correction	Substitute values at errors	Direct energy measurement
	Volume	Temperature pressure	Inside station	Outside station	Operating conditions	Normal conditions						
Belgium	1,2,3, 4,5,6	2,3	—	—	—	—	3[b]	1,2,3	2	—	2	—
China	1,2,3, 4,5,6	1,2,3,5, 6	1,2	—	—	—	1,2,3, 5,6	—	—	—	—	—
Germany	1,2,3, 4,5,6	1,2,3,5, 6	1	—	1,2,5	1,2,5, (1,2)[a]	1	1	1,2,5	1	1	—
France	1,2,3, 4,5,6	1,2,3,5, 6	1	—	(1,2)[a]	2 (1,2)[a]	1	1	1,2	—	1	—
United Kingdom	1,4,5,6	1,2,5,6	1	1	1 (1,2,5)[a]	1[a]	1	1	1,2,5	1	1	—
Italy	1,3,4, 5,6	1,3,5	1	—	1[a]	3,5 (1,3,5)[a]	1	1	1,3,5	—	1	—
Netherlands	1,2,3, 4,5,6	1,2,3,5, 6	1,2, 5,6	2	1 (1,2,5)[a]	1,2 (1,2, 3,5)[a]	1,2,4, 5,6	1,2,3, 4,5,6	1,2,3,5	5,6	1	—
Russian Federation	1,2,3, 4,5,6	1,2,3,4, 5,6	1,2, 3,4, 5,6		(1,2, 3,5)[a]	1,2,3,4, 5,6 (1,2, 3,5)[a]	1,2,3, 4,5,6	1,2,3, 4,5,6	—	—	1,2,3,4, 5,6	—
Hungary	1,3,4, 5,6	1,3,5,6	1	1	(1,3,5)[a]	(1,3,5)[a]	1	—	3,5	—	1	—
USA	1,2,3, 4,5,6	1,2,3,4, 5,6	1,2, 3,5,6	1,2,3, 5,6	1 to 6, (1 to 6)[a]	1,2,3,5,6 (1,2,3, 5,6)[a]	1,2,3, 5,6	1,2,3, 5,6	1,2,3,5	1,2, 3,5	1,2,3, 5,6	1,2,3,5

[a] Calculated density value.

[b] Plus Z-meter.

Table A.3

Country	Interface(s) at which the following activities take place							
	Density at		Temperature, pressure measurement	Calorific value measurement by				Backup of calorific value measurement
	Operating conditions	Normal conditions		GC	Wet calorimetry	Dry calorimetry	Other	
Belgium	—	(2,3,5,6)[a]	2,3,5,6	(2,3,5,6)[c]	—	—	—	2
China	(3,5)[a]	(3,5)[a]	3,5	(3,5)[d]	—	—	—	—
Germany	(1,2,5)[b]	(1,2,5)[b]; (1,2)[a]	1,2,3,5,6	(1,2,5)[c]; 2[d]	1,2,5	—	—	1,2
France	(1,2)[a]	(2,5)[b]; (1,2)[a]	1,2,3,5,6	(1,2)[c]	1	—	—	1,2
United Kingdom	1[b]; (1,2,5)[a]	1[a]	1,2,5,6	(1,2,5)[c]	—	—	—	1,2,5
Italy	1[a]	(3,5)[b]; (1,3,5)[a]	1,3,5	(1,5)[c]; (1,3,5)[d]	—	—	—	—
Netherlands	(1,5)[b]; (1,2,5)[a]	(1,2,5)[b]; (1,2,3,5)[a]	1,2,3,5,6	(1,2,5)[c]; 1[d]	1	—	—	1,2,5
Russian Federation	(1,2,3,5)[a]	(1,2,3,5)[a,b]	1,2,3,5,6	—	—	5	1,2,3,5	—
Hungary	(1,3,5)[a]	(1,3,5)[a]	1,3,5,6	(1,5)[c]	—	—	—	—
USA	(1,2,3, 5,6)[a,b]	(1,2,3, 5,6)[a,b]	1,2,3,4,5,6	(1,2, 3,5)[c,d]	1,2,3,5	1,2,3,5	—	1,2,3,5

[a] Calculated value.

[b] Measured value.

[c] Online.

[d] Offline.

Table A.4

Country	Interface(s) at which the following activities take place					
	Compressibility factor	**Volume conversion**	**Data storage**	**Generation of substitute values**	**Correction of metered calculated values by means of correction factor**	**Direct energy measurement**
Belgium	1[b,c]	1[d]	1[d,e]	1[f,g]	—	—
China	1,5[a]	1,5[d]	1[d]	—	—	—
Germany	1[b]	1[d]	1[d]	1[f,g]	1	—
France	1[b]	1[d]	1[d]	1[f,g]		—
United Kingdom	1[b]; 5[a]	1,5[d]; (4,5,6)[e]	1[d,e]	1[g]	1	—
Italy	1[a]	1[d]	1[d]	1[f,g]	—	—
Netherlands	(1,3,4,6)[a]; (2,4,6)[b]	(1,2,3,4, 5,6)[d]; 2[e]	(1,2,5,6)[d]; 2[e]	1[g]	5,6	—
Russian Federation	(1,2,3,4)[a]	(1,2,3,5)[d,e]	(1,2,3,5)[d]	(1,2,3,5)[f,g]	—	1,5
Hungary	(1,3,5)[a]; (1,3,5) [b]	(1,3,5)[d,e]	(1,3,5)[d,e]	(1,3,5)[f,g]	—	—
USA	(1,2,3,5,6)[a]	(1,2,3,5,6)[d,e]	(1,2,3,5,6)[d,e]	(1,2,3,5,6)[f]; (1,2,3,5)[g]	1,2,3,5	1,2,3,5

[a] Volume conversion by the AGA 8 method; see Reference [36].

[b] Volume conversion by the S-GERG88 method; see Reference [37].

[c] Z-meter.

[d] Inside station.

[e] Outside station.

[f] Local.

[g] Remote.

Table A.5

Country	Interface(s) at which the following activities take place						
	Energy determination on the basis of locally metered values	Energy values on the basis of calculated calorific values	Energy values, calculated on state reconstruction or mathematical models	Minimum time periods for energy determination for charging			
				Hourly	Daily	Monthly	Other
Belgium	2,3,5,6	4	4	2,3,5,6	3,5,6	5	(4,6)[c]
China	3,5	—	—	5	—	—	4[c], 5[a]
Germany	1,2,3,5	2,3,4,5,6	3,5	1,2,3,5,6	1,2,3	3,4,5,6	(4,6)[c]
France	1,2,3,5	3,4,5,6	3,5	1,2,5	1,2,3,5	3,4,6	4[a]
United Kingdom	1,2,5,6	1,4,5,6	—	—	1,4,5	5,6	4[b]
Italy	1,3,5	3,4,5,6	—	—	1,4,5	3,4,5,6	—
Netherlands	1,2,3,5	4,5,6	—	1,2,3,5	—	6	(4,6)[c]
Russian Federation	1,2,3,4,5,6	—	1,2,3,4,5,6	—	—	1,2,3,4,5,6	—
Hungary	1,3,5	3,4,5,6	—	—	1	3,4,5,6	4[c], 5[a]
USA	1,2,3,5	1,2,3,5	4,5,6	1,2,3	1,2,3,5	4,6	—

[a] Weekly.

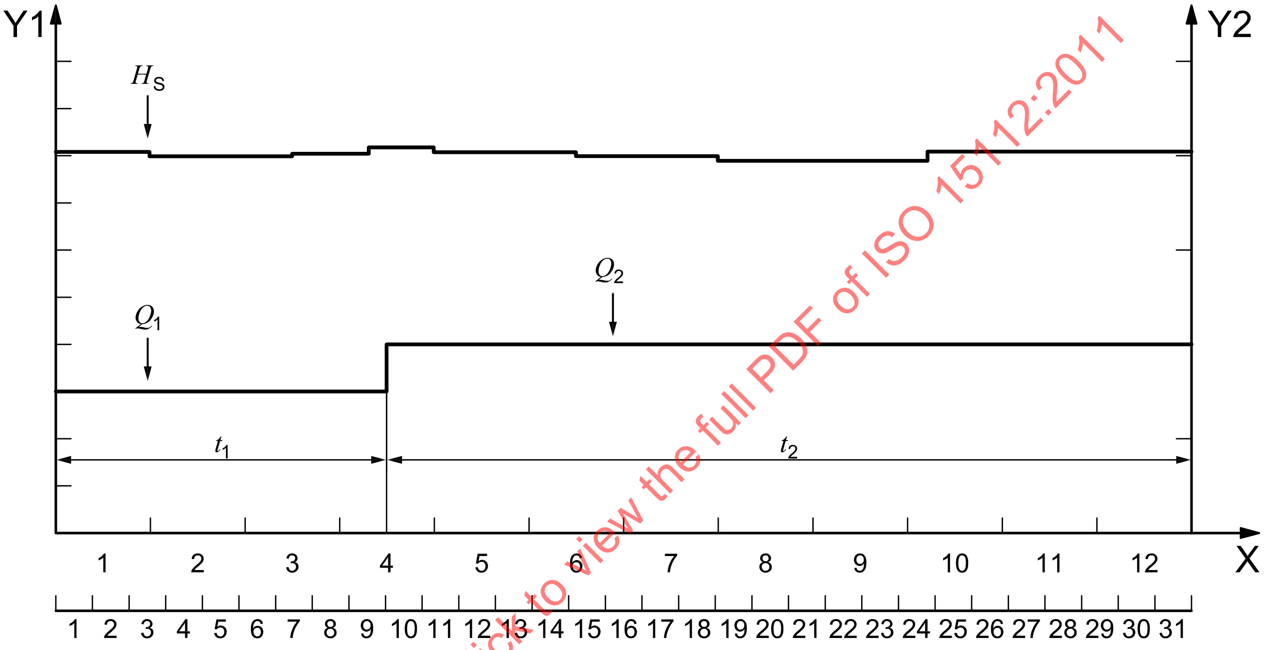
[b] Quarterly.

[c] Annually.

Annex B
(informative)

Different possible patterns in the change of the calorific value

Figures B.1 to B.3 show three different examples of possible patterns in the change of the calorific value for an energy-determination period.



Key

X months (1 = January, 12 = December) or days (1st to 31st of each month)

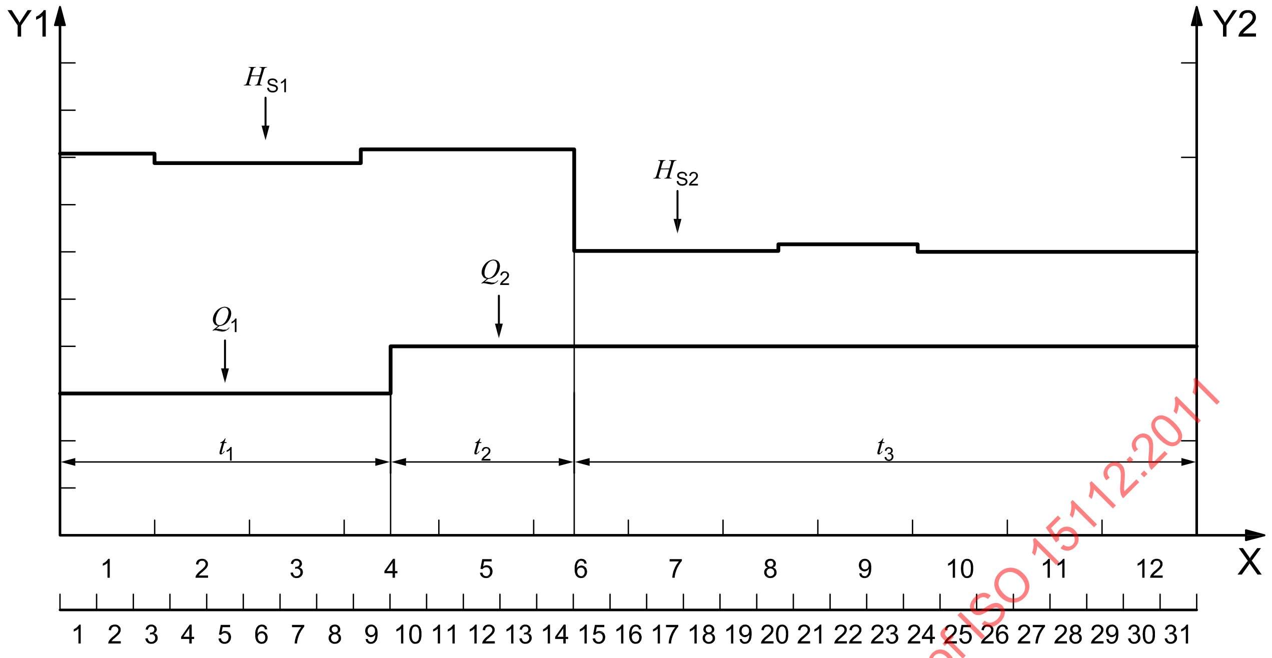
Y1 H_S, expressed in megajoules per cubic metre

Y2 q_v, expressed in cubic metres per day or cubic metres per month

Figure B.1 — Annual or monthly energy-determination period — Only normal changes in gas quality

In Figure B.1, the calorific value in a energy-determination period, for example one month, is nearly constant. Thus, it is justified to calculate an averaged calorific value for the complete month (see Clause 10 and especially 10.4 as a justified method). For energy determination, it is important to take into account that for the period from the 1st to the 10th, the gas flow rate was smaller than for the period from the 10th to 31st. Therefore, an energy quantity, E_1, can be calculated for the time period, t_1, and the energy quantity, E_2, for the time period, t_2.

If the time scale is one year, it is justified to calculate an annual averaged calorific value due to the shape of the calorific value curve. For such a year, an energy quantity, E_1, can be calculated for January to April, and for May to December an energy quantity, E_2.



Key

X months (1 = January, 12 = December) or days (1st to 31st of each month)

Y1 H_S, expressed in megajoules per cubic metre

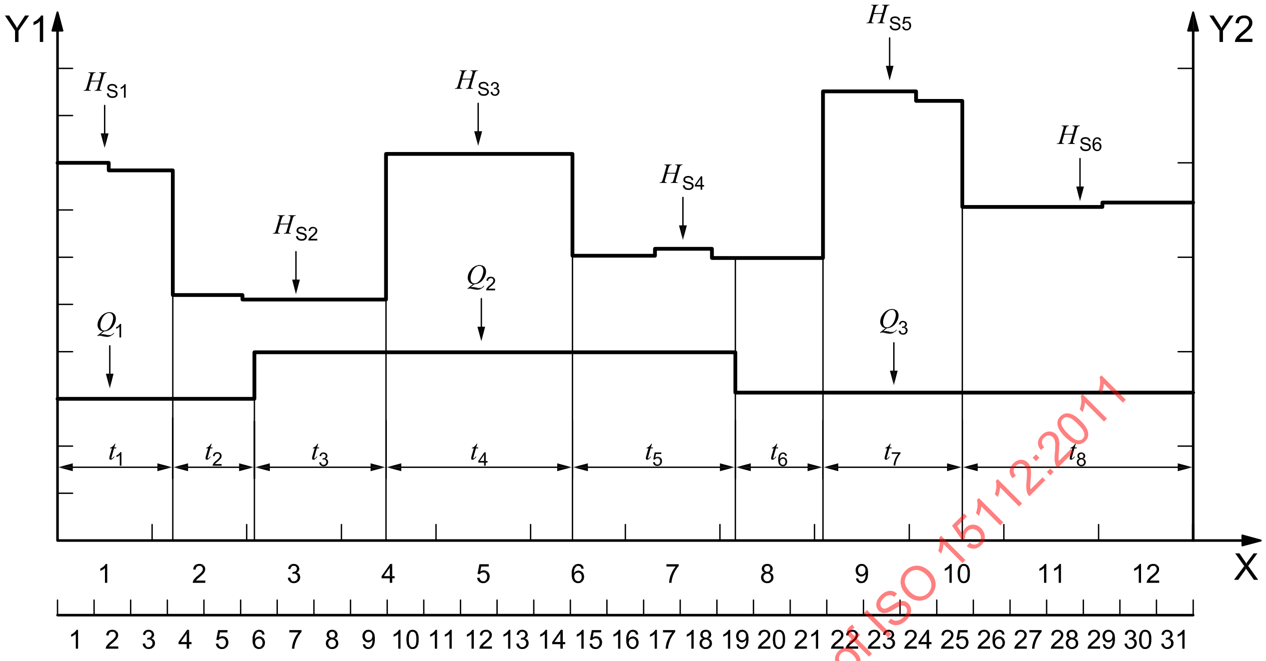
Y2 q_V, expressed in cubic metres per day or cubic metres per month

Figure B.2 — Annual or monthly energy-determination period — Two different calorific values

In Figure B.2, for example, the calorific value within the energy-determination period is nearly constant up to the 15th; the calorific value decreases then to a significantly lower level. For the energy determination, either the month shall be separated into two periods from the 1st to the 15th and from the 16th to the 31st, or an averaged calorific value shall be performed (see Clause 9 and Annex F). For large quantities and, therefore, for economical reasons, a separation into two periods shall be performed.

In this case, for energy-determination purposes, the energy quantities, E_1, E_2 and E_3, for the respective time periods, t_1, t_2 and t_3, shall be determined separately to compensate for the different quantities from the 1st to the 10th day and the change in calorific value at the 15th day.

If the time scale is one year, the patterns in the change of the calorific value justify separating the year into the determination periods, t_1, t_2 and t_3. Thus, the energy quantity, E_1, can be calculated for the period from January to April; E_2, for the period from May to June; and E_3, for the period from July to December.



Key

X months (1 = January, 12 = December) or days (1st to 31st of each month)

Y1 H_S, expressed in megajoules per cubic metre

Y2 q_v, expressed in cubic metres per day or cubic metres per month

Figure B.3 — Annual or monthly energy-determination periods — Several different calorific values

In Figure B.3, the calorific value within an energy-determination period, for example one month, changes several times; thus, either the month shall be separated into a couple of periods or an averaged calorific value shall be calculated (see Clause 9 and Annex F). For large quantities and, therefore, for economical reasons, a subdivision shall be made to take the calorific values H_{S1} to H_{S6} into account individually.

In this case, the energy quantities, E_1 to E_8, associated with the time periods t_1 to t_8, respectively, are calculated separately, using the different quantities, Q_1, Q_2 and Q_3, and the different calorific values associated with each time period. The total energy quantity is obtained by summing the E_1 to E_8 values [see Equation (5)].

If the time scale is one year, the patterns in the change of the calorific value justify separating the year into different energy-determination periods with H_{S1}, H_{S2}, H_{S3}, etc. and to determine for each period an averaged calorific value for energy determination.

Annex C
(informative)

Volume conversion and volume-to-mass conversion

As the common International Standards for flow (ISO 5167-1, ISO 9951 and ISO/TR 12765) generally provide the flow rate in mass per second or volume (under operating conditions) per second, in the latter case a conversion to volume under reference conditions is necessary.

Starting from the continuity in mass, EN 1776:1998, Annex C, derives equations for volume conversion and determination of mass from volume and density under operating conditions. These are given, using symbols conforming with the ISO directives, as Equations (C.1) and (C.2) for calculating the converted volume, V_r, under reference conditions, expressed in cubic metres, and Equation (C.3) for calculating the mass, M, expressed in kilograms.

Equations (C.1) to (C.3) can be used for calculations relevant to this International Standard.

$$V_\mathrm{r} = V \cdot \frac{p \cdot T_\mathrm{r} \cdot Z_\mathrm{r}}{p_\mathrm{r} \cdot T \cdot Z} \tag{C.1}$$

$$V_\mathrm{r} = V \cdot \frac{\rho}{\rho_\mathrm{r}} \tag{C.2}$$

$$M = V \cdot \frac{p \cdot M_\mathrm{m}}{T \cdot Z \cdot R} \tag{C.3}$$

where

p is the pressure under operating conditions, expressed in kilopascals (bar);

p_r is the pressure under ISO-recommended reference conditions, expressed in kilopascals (bar);

T is the operating temperature, expressed in kelvins;

T_r is the ISO-recommended reference temperature, expressed in kelvins;

V is the volume under operating conditions, expressed in cubic metres;

Z is the compression factor under operating conditions;

Z_r is the compression factor under ISO-recommended reference conditions;

NOTE For compression factor, see 6.4.4.

M_m is the molar mass, expressed in kilograms per mole;

R is the universal gas constant, equal to 8,314 510 kJ/(kmol × K);

ρ is the density under operating conditions, expressed in kilograms per cubic metre;

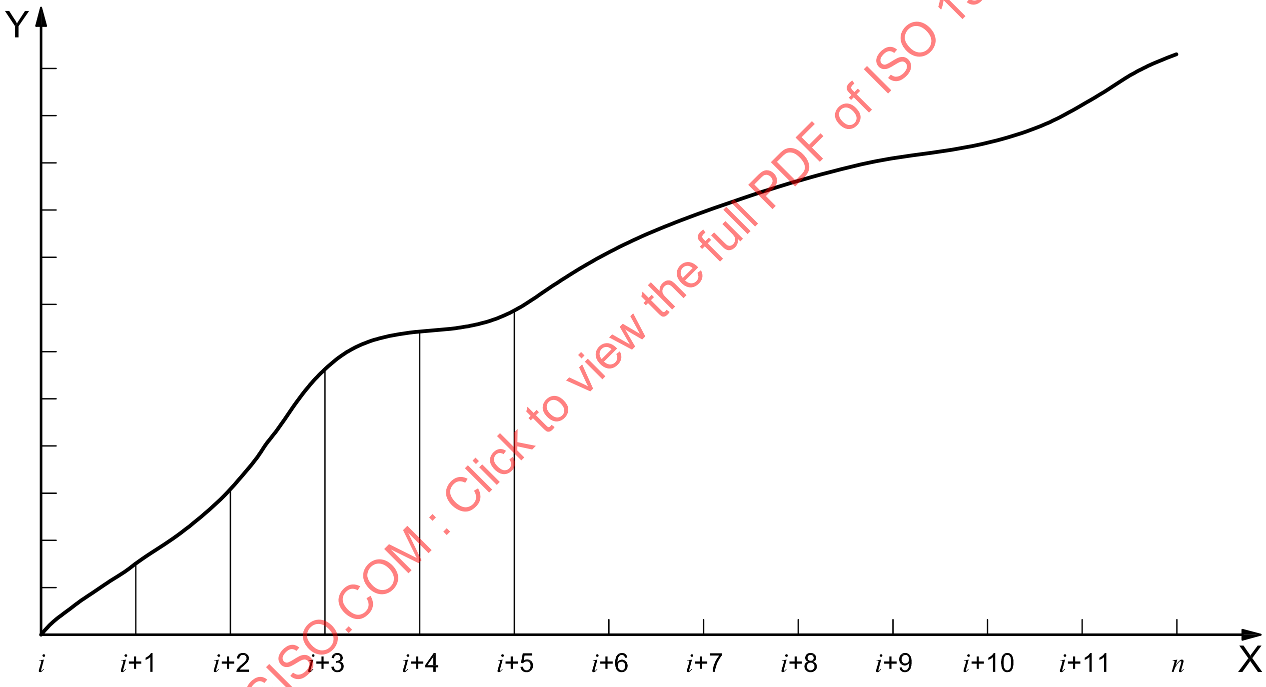
ρ_r is the density under the ISO-recommended reference conditions, expressed in kilograms per cubic metre.

Annex D
(informative)

Incremental energy determination

In this method, measurements of the calorific value are made at short intervals of time and are multiplied by the quantity of gas registered by the meter in the interval between successive measurements to obtain the quantity of energy for that interval. The time intervals are typically a few minutes, the only requirement being that the calorific value of the gas should remain essentially constant over the chosen time interval.

In many cases, the time interval is equal to the cycle time of the GC used to determine the calorific value. The individual quantities of energy for all the time intervals in the billing period are then added together to give the energy. The method is illustrated in Figure D.1.



Key

X time ($t = i, i+1, i+2, ..., j$)

Y metered quantity of gas

Figure D.1 — Incremental energy determination

At time i, the quantity of gas registered on the meter is $Q_{t=i}$ and the calorific value of gas is measured as $H_{t=i}$.

At time $i+1$, the quantity of gas registered on the meter is $Q_{t=i+1}$ and the calorific value is measured as $H_{t=i+1}$.

Then the quantity of energy for the interval from $t = i$ to $t = i + 1$ is given in Equation (D.1):

$$E_{t=i\ \text{to}\ t=i+1} = (Q_{t=i+1} - Q_{t=i}) \cdot H_{t=i} \tag{D.1}$$

Then, for any period from time i to time j, the total energy, E, is obtained by adding together all the discrete portions of energy, as given in Equation (D.2):

$$E = (E_{t = i \text{ to } t = i + 1} + E_{t = i + 1 \text{ to } t = i + 2} + \dots\dots\dots\dots + E_{t = j - 1 \text{ to } t = j}) \tag{D.2}$$

Practically, this method is implemented using a flow computer to record the quantity of gas registered by the flow meter and the calorific value measurements being input into the flow computer.

Generally, this method is found where both quantity and quality measurements are carried out at the interface. However, state-of-the-art information systems can be used to provide online, fixed-assignment calorific values that can be used in this method.

Annex E
(informative)

Practical examples for volume conversion and energy quantity calculation

E.1 Calculations using ISO 12213-3

E.1.1 General equations

The calculation of the volume, V_n, expressed in cubic metres under normal reference conditions, from the volume under operating conditions is given by Equation (E.1):

$$V_\mathrm{n} = V \cdot z \tag{E.1}$$

where

V is the volume under operating conditions, expressed in cubic metres;

z is the z-factor, calculated as given in Equation (E.2):

$$z = \frac{T_\mathrm{n}}{T} \cdot \frac{p_\mathrm{amb} + p_\mathrm{g} - p_\mathrm{H_2O}}{p_\mathrm{n}} \cdot \frac{Z_\mathrm{n}}{Z} \tag{E.2}$$

where

T_n is the temperature under normal reference conditions, expressed in kelvins;

T is the operating temperature, expressed in kelvins;

p_amb is the average of the ambient air pressure at the meter, expressed in kilopascals (bar);

p_g is the operating pressure (gauge), expressed in kilopascals (bar);

$p_\mathrm{H_2O}$ is the partial pressure of water in natural gas, expressed in kilopascals (bar);

ρ_n is the density under normal reference conditions, expressed in kilograms per cubic metre;

Z is the compression factor under operating conditions;

Z_n is the compression factor under normal reference conditions.

Z_n/Z can be calculated from H_S, ρ_n, and the concentrations of CO_2, N_2 and H_2, for example using ISO 12213-3 (S-GERG88; see Reference [37]).

E.1.2 Example calculation

The calculation for the converted volume, V_n, is carried out as demonstrated using the following parameters, as given in ISO 12213-3 (S-GERG88; see Reference [37]):

- average of the ambient air pressure at the meter, p_{amb} 99,66 KPa (0,996 6 bar);
- operating pressure (gauge), p_g 700 KPa (7,0 bar);
- operating temperature, T 288,15 K;
- calorific value, $H_{S,n}$ 11,901 kWh/m^3;
- density, ρ_n 0,822 7 kg/m^3;
- concentration of CO_2, C_{CO_2} 1,12 mol %;
- concentration of N_2, C_{N_2} 0,80 mol %;
- concentration of H_2, C_{H_2} 0 mol %;
- partial pressure of water in natural gas, p_{H_2O} $<$ 0,1 KPa ($<$ 0,001 bar);

  NOTE 1 p_{H_2O} can be expressed by the product of φ (relative humidity of the gas) and p_{sat} (partial pressure of steam in saturated gases); in dry natural gases p_{sat} is usually $p_{sat} \leqslant 0,1$ KPa (0,001 bar). Thus, for dry natural gases the expression ($p_{H20} = \varphi \cdot p_{sat}$) can usually be set to zero.

- Z_n/Z ratio 1,017 52.

  NOTE 2 This value is calculated using the first eight values above in ISO 12213-3 (S-GERG 88; see Reference [37]).

The substitution of the measured values into Equation (E.2) results in the following:

$$z = \frac{273{,}15\ \text{K}}{288{,}15\ \text{K}} \cdot \frac{099{,}66\ \text{kPa} + 70\ \text{kPa} - 0\ \text{kPa}}{101{,}325\ \text{kPa}} \cdot 1{,}017\ 52$$

$$z = 0{,}947\ 94 \cdot 7{,}892\ 03 \cdot 1{,}017\ 52$$

$$z = 7{,}612\ 24$$

At a measurement station, a quantity, Q [$V = 1\ 000$ m^3; $T = 288{,}15$ K; $p_g = 700$ kPa (7,0 bar); $p_{amb} = 99{,}6$ kPa (0,996 6 bar)], has been measured. Performing the volume conversion to normal conditions using Equation (E.1) yields

$$V_n = 7\ 612{,}24\ \text{m}^3$$

The energy quantity, E, is calculated in accordance with Equation (10) as given below.

$$E = 7\ 612{,}24\ \text{m}^3 \cdot 11{,}901\ \text{kWh/m}^3$$

$$E = 90\ 593{,}27\ \text{kWh} = 326\ 135{,}77\ \text{MJ}$$

E.2 Calculations using ISO 12213-2

E.2.1 General equations

The same general equations and principles as given in E.1.1 hold, except that Z_n/Z can be calculated from the gas analysis, using ISO 12213-2.

E.2.2 Example calculation

The calculations for the energy, E, are carried out as demonstrated using the following parameters, measured at one of the interfaces.

— average of the ambient air pressure at the meter, p_{amb}	99,66 KPa (0,996 6 bar);
— operating pressure (gauge), p_g	5 000 KPa (50,0 bar);
— operating temperature, T	283,15 K;
— concentration of CO_2, C_{CO_2}	2,22 mol %;
— concentration of N_2, C_{N_2}	0,77 mol %;
— concentration of O_2, C_{O_2}	0,01 mol %;
— concentration of CH_4, C_{CH_4}	87,62 mol %;
— concentration of C_2H_6, $C_{C_2H_6}$	8,75 mol %;
— concentration of C_3H_8, $C_{C_3H_8}$	0,53 mol %;
— concentration of i-C_4H_{10}, $C_{i\text{-}C_4H_{10}}$	0,03 mol %;
— concentration of n-C_4H_{10}, $C_{n\text{-}C_4H_{10}}$	0,04 mol %;
— concentration of i-C_5H_{12}, $C_{i\text{-}C_5H_{12}}$	0,01 mol %;
— concentration of n-C_5H_{12}, $C_{n\text{-}C_5H_{12}}$	0,01 mol %;
— concentration of C_6H_{14+}, $C_{C_6H_{14+}}$	0,01 mol %;
— calorific value (calculated from analysis), $H_{S,n}$	11,581 kWh/m^3;
— density (calculated from analysis), ρ_n	0,813 3 kg/m^3;
— partial pressure of water in natural gas, p_{H_2O}	< 0,1 KPa (< 0,001 bar);

NOTE 1 p_{H_2O} can be expressed by the product of φ (relative humidity of the gas) and p_{sat} (partial pressure of steam in saturated gases); in dry natural gases, p_{sat} is usually $p_{sat} \leqslant$ 0,1 KPa (0,001 bar). Thus, for dry natural gases the expression ($p_{H20} = \varphi \cdot p_{sat}$) can usually be set to zero.

— Z_n/Z ratio:	1,152 073 7.

NOTE 2 This value is calculated using the concentrations CO_2 to C_6H_{14+} in ISO 12213-2 {AGA:8-92DC, Equation (8); see Reference [36]}.

The substitution of the measured values into Equation (E.2) results in the following:

$$z = 0{,}964\,68 \cdot 50{,}329\,73 \cdot 1{,}152\,073\,7$$

$$z = 55{,}935\,58$$

At a measurement station, a quantity, Q [$V = 10\,000$ m^3; $T = 283{,}15$ K; $p_g = 5\,000$ kPa (50,0 bar); $p_{amb} = 99{,}66$ kPa (0,996 6 bar)], has been measured. The volume is converted to V_n under normal conditions using Equation (E.1):

$$V_n = 559\,355{,}8 \text{ m}^3$$

The energy quantity, E, is calculated in accordance with Equation (10):

$$E = 559\,355{,}8 \text{ m}^3 \cdot 41{,}6916 \text{ MJ/m}^3$$

$$E = 23\,320\,438{,}27 \text{ MJ} = 6\,477\,899{,}52 \text{ kWh}$$