

English Version

**Specification for portable electrical apparatus designed to
measure draught and gas pressure of heating appliances and
systems**

Spécification pour les appareils électriques portatifs conçus
pour mesurer la pression du tirage et des gaz dans les
conduits d'évacuation des appareils et systèmes de
chauffage

Anforderungen an tragbare elektrische Geräte zur Messung
des Differenzdrucks und des Gasdruckes von
Heizungsgeräten und -anlagen

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European foreword

This document (EN 50725:2025) has been prepared by CLC/TC/216 “Gas Detectors”.

The following dates are fixed:

- latest date by which this document has to be implemented at national level by publication of an identical national standard or by endorsement (dop) 2026-02-28
- latest date by which the national standards conflicting with this document have to be withdrawn (dow) 2028-02-29

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1 Scope

This document specifies the requirements and test methods concerning, in particular the construction, safety, and fitness for purpose, as well as the capability and marking of a hand-held battery powered pressure and leakage measurement instrument, hereafter referred to as “pressure meters”, for gas pipework in buildings, gas pipes of appliances and draught in chimneys.

NOTE Areas of application can be supply pressure of gas appliances, nozzle pressure of gas appliances (see relevant instruction manuals of gas appliances) as well as strength test, tightness test and fitness test of gas pipework as defined in EN 1775 (see Annex A) and relevant national standards (see Annex B) for gas pipework in buildings, and draught measurement in chimneys of heating appliances.

This document covers pressure meters with the capability of

- use with air, natural gas, liquid petroleum gas (LPG), hydrogen and mixtures of natural gas and hydrogen,
- measuring pressure in units of bar, mbar, Pa, hPa, kPa, MPa, in H₂O, mm H₂O, or PSI,
- measuring leakage rate in l/h,
- withstanding the every-day working environment encountered by installation and service engineers in domestic, commercial, or industrial premises.

Such pressure meters might be capable of

- being switchable between units by the user,
- storing and/or transmitting said measurements to a remote user.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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.

EN IEC 61326-1, *Electrical equipment for measurement, control and laboratory use — EMC requirements — Part 1: General requirements (IEC 61326-1)*

EN 50271:2018, *Electrical apparatus for the detection and measurement of combustible gases, toxic gases or oxygen — Requirements and tests for apparatus using software and/or digital technologies*

EN 60068-2-6, *Environmental testing — Part 2-6: Tests — Test Fc: Vibration (sinusoidal) (IEC 60068-2-6)*

EN IEC 60335-1:2023,¹ *Household and similar electrical appliances — Safety — Part 1: General requirements (IEC 60335-1:2020)*

EN 60529:1991,² *Degrees of protection provided by enclosures (IP Code)*

ISO/IEC Guide 98-3:2008, *Uncertainty of measurement — Part 3 — Guide to the expression of uncertainty in measurement (GUM: 1995)*

¹ As impacted by EN IEC 60335-1:2023/A11:2023.

² As impacted by EN 60529:1991/corrigendum May 1993, EN 60529:1991/AC:2016-12, EN 60529:1991/A1:2000 and EN 60529:1991/A2:2013.

3 Terms and definitions

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

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at <https://www.iso.org/obp>
- IEC Electropedia: available at <https://www.electropedia.org/>

3.1

domestic residential and commercial premises

any place of residence of a household, family or person (whether temporary or permanent) and commercial premises whether residential or not and including recreational boats, caravans and mobile homes

3.2

sensors

assembly in which the sensing element is housed and which may contain associated circuit components

3.3

sensing element

device, the output of which will change with variation of the parameter of interest

3.4

spot reading

apparatus intended to be used for short periods of time in the range of minutes, as required

3.5

mains powered apparatus

apparatus designed to be powered by the domestic mains electrical supply with or without an additional power source

3.6

battery powered apparatus

apparatus designed to be energised from batteries alone, whether disposable or rechargeable

3.7

sampling point connector

part of the apparatus that is used to connect the apparatus to the appliance for the purpose of sampling the pressure

3.8

initial start up delay

time taken for the apparatus to reach the operating mode from switch-on, or after replacing batteries, or following power failure in the case of mains powered equipment

3.9

calibration

process of determining the deviation of an apparatus relative to a reference

3.10

reference

in laboratory tests, a measuring device with certification proving traceability to a national or international metrology institute

3.11**adjustment**

process of tuning the apparatus, in order to return the deviation found in calibration to within the admissible error

3.12**functional module**

all components required for one measurement task, including both hardware and software

Note 1 to entry: A functional module may consist of one or more separate pieces of equipment or may be completely integrated with the apparatus.

3.13**response time (t_{90})**

time interval with the apparatus in a warmed-up condition, between the time when an instantaneous variation of the parameter to be measured is produced at the apparatus inlet, and the time when the response reaches and remains beyond 90 % of the final indication

3.14**gas leakage rate**

volume flow (unit l/h) of burnable gas that escapes from the line system during a specified duration due to leakage

3.15**standard volume flow**

volume flow (unit l/h) with reference to the physical standard temperature and pressure at a temperature of 273,15 K and a pressure of 1 013,25 hPa

3.16**operating volume flow**

volume flow (unit l/h) with reference to the operating conditions (pressure, temperature) prevailing at the place of measurement

3.17**operating pressure**

actual operating pressure as standing pressure found at the time of measurement

3.18**reference operating pressure**

reference pressure for determining the leakage quantity as operating volume flow

4 General requirements**4.1 General**

The apparatus shall reliably measure the applied pressure and shall clearly display the result.

4.2 Construction**4.2.1 General**

All parts of the apparatus, including the sensors, shall be constructed of materials that will not be adversely affected by vapours and gases or chemical substances to be expected during normal operation of the apparatus, see 4.3.2 g). Similar consideration shall also be given to the sampling system and components that can be in contact with the measuring medium, as appropriate. The sampling point connector shall be constructed of materials that will not be adversely affected by environmental conditions found in applications within the scope of this document.

4.2.2 Sampling system

The method of testing tightness of the complete gas sampling system, as specified by the manufacturer or installer, shall be checked and verified in practice.

4.2.3 Adjustment

Access to sensitivity controls shall only be possible by the use of special tool or a software pass-code or by destroying a special seal. Any regular checks shall be performed automatically or by access as described above.

4.2.4 Power supply

Apparatus which derives its power from internal batteries may give a visual warning before the battery capacity falls to a point where either the apparatus sensitivity or the stated display accuracy falls outside the requirements. When this point is actually reached, a clear indication shall be given to alert the user and the display shall switch out of normal operational mode.

4.2.5 Display

Indicators shall be provided to show the following:

- measured value(s) and physical unit;
- low battery warning;
- mode of operation or instrument status (e.g. warm-up, measurement);
- when values lie outside the indicating range; and
- software version.

For each separate parameter measured, the apparatus shall display the value, the physical unit and parameter description. For a combination of parameters, the display may switch automatically from one indication to another. If the display switches between information of simultaneous parameters it shall be clear and understandable. Displayed measured values shall be refreshed at intervals no greater than 3 s. If the apparatus is equipped with seven-segment displays it shall have a device or self-testing function for checking the displays.

4.2.6 Measuring range and resolution

Table 1 lists the different parameters covered by this document. For each parameter given it specifies:

- minimum indication range;
- minimum display resolution;
- accuracy of the apparatus;
- the detection limit; and
- maximum response time.

4.2.7 Indication range

The indication ranges are the minimum ranges for the apparatus. Higher ranges are allowed but will not change the values for accuracy or detection limit.

4.2.8 Accuracy of the apparatus

The values in Table 1 e.g. “ ± 20 Pa or 5 % rel.” have the meaning: “The permitted deviation is up to ± 20 Pa or ± 5 % of the reading, whichever is the greater”.

4.2.9 Detection limit

Values Indicated below the detection limit are not significant.

Table 1 — Requirements for accuracy

Parameter	Indication range	Display resolution	Accuracy	Detection limit	Response time t ₉₀
Low range	–50 Pa to +200 Pa	1 Pa	± 2 Pa or 5 % rel.	1 Pa	10s
Mid-range	0 Pa to 20 000 Pa	10 Pa	± 50 Pa or 3 % rel.	100 Pa	10 s
High range	0 Pa to 300 000 Pa	100 Pa	± 200 Pa or 3 % rel.	500 Pa	10 s
Leakage rate	0 to 8 l/h	0,1 l/h	± 0,2 l/h or ± 5 % rel.	0,1l/h	N/A

4.2.10 Printer or data storage or transmission

If the apparatus is provided with a printer or any means for data storage or transmission e.g. a data logger it shall print, store or transmit the date, time and values or parameters, as specified in 4.2.6, taken at the time of the printout.

4.2.11 Averaging

Averaging readings during a test is permitted but only to give a more stable reading for recording. The method of averaging shall be included in the manual and its selection shall be recorded with the test results.

NOTE Time periods for averaging can be found in national regulations, though these time periods might vary from one another.

4.3 Labelling and Instructions

4.3.1 Labelling

Durable label(s) shall be carried on the apparatus, or moulded into the casing, giving at least the following information:

- the manufacturer's or supplier's name, trademark, Measurement range or other means of identification;
- the type of apparatus, e.g. “combustion appliance pressure meter”, and model name or number;
- either the number of this Standard or the third-party certification;
- the manufacturer's serial number and/or production batch date code;
- the replacement battery and mains power requirements, as relevant;
- whether or not the instrument is suitable for outdoor use (see 5.3.2).

Item (e) shall be clearly visible if the batteries are being changed.

External label(s) shall comply with EN IEC 60335-1:2023,¹ 7.6 and 7.14.

4.3.2 Instructions

The apparatus shall be provided with an instruction manual giving complete, clear and accurate instructions for the safe and proper operation and regular checking of the apparatus. It shall also include the following:

- a) a statement of compliance to this European Standard;
- b) the specific type(s) of gas medium for which the apparatus is intended to be used;
- c) the correct battery type(s) and method of replacing or recharging batteries, for battery powered units, details of mains voltage, frequency, and fuse rating, if relevant, and a warning of the possible hazards of electric shock or malfunction, if tampered with;
- d) warnings against continuous use, or use as a safety alarm;
- e) an explanation of all indications;
- f) the recommended minimum time required to perform one complete measurement cycle and achieve correct indication of the measured value(s);
- g) a list of commonly occurring materials, vapours or gases (e.g. cleaning fluids, polishes, paints, cooking operations, etc.) which may affect the operation or reliability of the apparatus, in the short or long-term;
- h) guidance on the life expectancy of the sensor(s) and batteries;
- i) details of operational limitations, including ambient temperature and humidity ranges, and whether the apparatus is intended to be placed in an appropriate case during transportation and/or normal operation;
- j) details of initial start up delay following switch on and after battery replacement;
- k) instructions for checking, testing and/or replacing sensing elements (where applicable) and calibration and/or adjustment of the apparatus on a routine basis;
- l) a warning that, when using the apparatus, a full visual inspection of the appliance shall also be carried out to ensure its safe operation;
- m) instructions for testing and/or sampling system;
- n) all user changeable parameters and their valid ranges;
- o) life time of data storage if a back-up battery is used for preserving the data content of parameter memory when the supply voltage is removed.

5 Test methods

5.1 General requirements for tests

5.1.1 General

The manufacturer should specify which gas medium, or range, shall be used during the tests.

If the apparatus has a modular structure allowing different types of practical measurements it should clearly state in the manual which parameters and combinations are to be used for which application.

5.1.2 Samples and sequence of tests

Details of the samples needed and the sequence of testing to be followed are defined, as appropriate. Tests shall first be carried out to ensure that the apparatus satisfies the constructional requirements of 4.2 and the requirements for labelling and instructions of 4.3 as appropriate.

5.1.3 Preparation of samples

The sample apparatus shall be prepared in accordance with the manufacturer's instructions. If the apparatus is normally used in its carrying case then the test shall be carried out with the apparatus in the carrying case.

5.2 Normal conditions for tests

5.2.1 General

The normal test conditions in 5.2.2 to 5.2.5 shall be used for all tests unless otherwise specified.

5.2.2 Pressure tests

The apparatus will be tested to the ranges shown in Table 1 as appropriate.

For the low range adjust a suitable pressure source to the reference pressures of + 20 Pa, + 70 Pa and + 190 Pa, within ± 2 Pa in each case.

For the high range adjust a suitable pressure source to the reference pressures of 1 000 Pa, 5 000 Pa and 9 900 Pa, within ± 200 Pa in each case.

5.2.3 Power supply

Unless otherwise specified for the particular test mains voltages shall be within +2 % of the nominal values quoted by the manufacturer. Battery powered apparatus shall be fitted with new or fully charged battery/batteries at the start of each test, where appropriate.

5.2.4 Temperature

Unless otherwise specified for the particular test the ambient temperature shall be at a constant temperature ± 2 °C, within the range 15 °C to 25 °C for the duration of each test.

5.2.5 Humidity

Unless otherwise specified for the particular test the ambient air shall be at a constant relative humidity ± 10 % within the range 30 % to 70 % for the duration of each test.

5.2.6 Pressure

Unless otherwise stated for the particular test the ambient pressure shall be at a constant pressure ± 1 kPa within the range of 86 kPa to 108 kPa throughout the duration of the test.

5.3 Mechanical tests

5.3.1 General

If the apparatus is designed to be used in a protection case this shall be clearly mentioned in the instruction manual and shall be subjected to the mechanical test from 5.3.3 to 5.3.5 in this protection case.

5.3.2 Degree of protection

The enclosure of the apparatus shall provide at least an IP40 degree of protection when all probes etc are connected, in accordance with EN 60529:1991,² Clauses 12 and 14. If an apparatus is designed for outdoor use it shall provide at least an IP42 degree of protection when connected similarly. The apparatus shall be tested in accordance with EN 60529:1991,² Clauses 12 and 14.

5.3.3 Impact strength

The apparatus shall be tested in accordance with the test specified in EN IEC 60335-1:2023, Clause 21, with the following modification to the third paragraph:

“The apparatus is rigidly supported, and three blows are applied to every point of the enclosure that is likely to be weak with an impact energy of $(1,0 \pm 0,2)$ J”.

5.3.4 Vibration

The appropriate test, as defined in EN 60068-2-6, shall be applied with the following parameters:

- frequency range 10 Hz to 150 Hz;
- vibration amplitude 0,35 mm;
- duration of endurance 10 sweep cycles per axis.

The test may be replaced by the procedure 1 from EN 60079-29-1.

Mount the apparatus in its normal operating orientation and apply the vibration along each of the three mutually perpendicular major axes in turn. Subject the apparatus to one of the most appropriate test gas mixtures as described in 5.2.2.

5.3.5 Drop

Drop the apparatus, including the probe and any Interconnecting wiring and tubing, in its normal operating orientation from a height of 0,5 m onto concrete. The apparatus shall be subjected to this test in a case intended to provide protection during transportation if one is supplied with the apparatus. Subject the apparatus to one of the most appropriate test gas mixtures as described in 5.2.2.

5.4 Electrical and software tests

5.4.1 Electromagnetic Compatibility (EMC)

Test the apparatus, including the probe and any interconnecting wiring and tubing, for electromagnetic compatibility in accordance with EN IEC 61326-1.

5.4.2 Supply voltage variations (not applicable to battery powered apparatus)

Power the equipment at the rated supply voltage U_n and frequency. Subject the apparatus to one of the test gas mixtures for all gas parameters to be tested as described in 5.2.2, at a rated supply voltage of $U_n + 10\%$. Repeat the test at a supply voltage of $U_n - 10\%$.

5.4.3 Battery fault conditions (applicable only to battery powered apparatus)

Connect the apparatus to a stabilized power supply and set to the rated battery voltage. Decrease the supply voltage in steps of 0,1 V, at intervals of at least 1 min, until the battery fault warning is given. Record the supply voltage at which the fault condition is given as U_e . Set the supply voltage one step above U_e . And subject the apparatus to one of the test gas mixtures for all gas parameters to be tested as described in 5.2.2.

5.4.4 Battery reversal (only applicable to battery powered apparatus)

The battery reversal test shall be applied to apparatus incorporating replaceable batteries if there is any possibility of the apparatus being subjected to reversed polarity of supply during normal battery replacement. In this case, remove the battery and insert it into the apparatus with reverse polarity, switch on the apparatus, then remove the battery and reinsert it with correct polarity. Switch on the apparatus and subject it to one of the test gas mixtures for all gas parameters to be tested as described in 5.2.2.

5.4.5 Software and digital techniques

Software and digital components shall comply with EN 50271:2018, 4.1.1 to 4.1.3, 4.4, 5.1 and 5.2 including 5.1.c requiring software documentation according to 4.3.4.

5.5 Tests with pressure supply

5.5.1 General

There shall be no adjustment of the apparatus, except where noted, during the whole sequence of tests 5.5.2 to 5.5.6.

Pressure measurements:

- i) zero the apparatus following manufacturer's instructions;
- ii) connect the apparatus to a suitable pressure source and apply the lowest pressure in 5.2.2;
- iii) repeat i) and ii) for pressure inputs in increasing value in 5.2.2.

5.5.2 Unpowered storage

The apparatus (including the battery, if the manufacturer supplies this item with the product) shall be exposed sequentially to a temperature of $(-20 \pm 2) ^\circ\text{C}$ for 24 h, ambient temperature for 24 h, $(50 \pm 2) ^\circ\text{C}$ for 24 h and ambient for 24 h. The apparatus shall then be energized and subjected to each of the input sources in 5.2.2 following the method described in 5.5.1.

5.5.3 Initial performance test

The apparatus shall be tested with all relevant pressure inputs in accordance with 5.2.2 following the method described in 5.5.1 at $(5 \pm 2) ^\circ\text{C}$, or $(-5 \pm 2) ^\circ\text{C}$ for equipment designed for outdoor use, after being exposed to that temperature for at least 1 h. The apparatus shall be allowed to stabilize at $(20 \pm 2) ^\circ\text{C}$ for at least 1 h. The apparatus shall then be tested again with all relevant pressure inputs in accordance with 5.2.2 following the method described in 5.5.1 at $(40 \pm 2) ^\circ\text{C}$, after being exposed to that temperature for at least 1 h.

5.5.4 Response time

Zero the apparatus and connect to the maximum value, in the relevant range, from 5.2.2. Measure the time between applying the test pressure and the displayed value reaching 90 % of the applied pressure.

5.5.5 Cold start

Store the complete apparatus and accessories at $(0 \pm 2) ^\circ\text{C}$ for at least 2 h, then transfer the whole apparatus to $(20 \pm 2) ^\circ\text{C}$ and not more than 50 % RH and immediately switch on, following the manufacturer's instructions. After a further 10 min zero the apparatus and connect to the maximum value, in the relevant range, from 5.2.2 following the method described in 5.5.1.

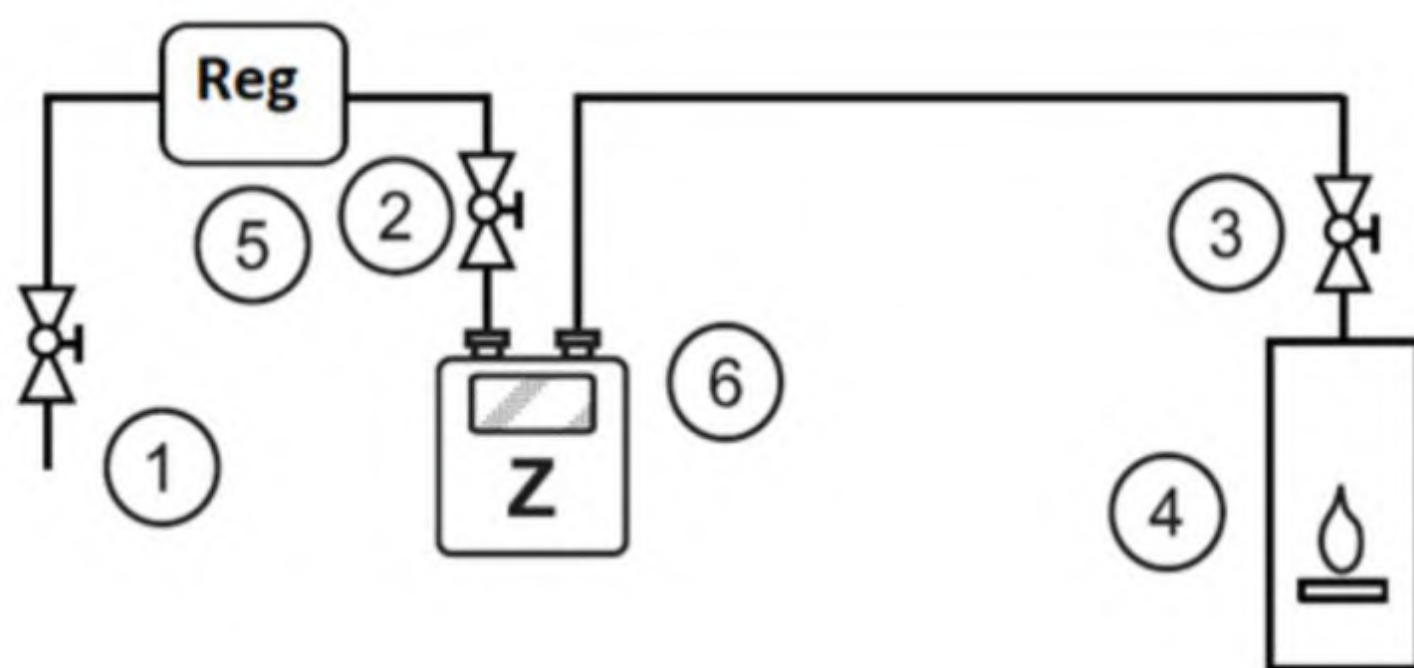
5.5.6 Ambient pressure variation

A test shall be carried out with the maximum value input pressure, as appropriate to the apparatus under test, as described in Table 1 to be tested in accordance with 5.2.2 following the method described in 5.5.1 at $(95 \pm 0,5) \text{ kPa}$, $(100 \pm 0,5) \text{ kPa}$, and $(105 \pm 0,5) \text{ kPa}$. The pressure shall be maintained at the specified levels for 5 min, before a reading is accepted or a test is made.

Annex A (informative)

National situations for strength test, tightness test and fitness test of gas pipework with reference to EN 1775 and EU 426/2016

A.1 Gas installation example



Key

- 1 Main isolation valve
- 2 Meter-isolation valve
- 3 Gas appliance isolation valve
- 4 Gas appliance
- 5 Pressure regulator
- 6 Gas meter

Figure A.1 — Example of a possible gas installation in Germany

A.2 Strength test according to EN 1775 and national implementation for maximum operating pressure up to 100 kPa

Test system: Pipework without components like: valves, pressure regulator, gas meter, gas appliance.

Valves may be included if the maximum operating pressure (MOP) is equal to test pressure.

Test medium Air or Inert gas (e.g. N₂).

Table A.1 — National parameters for strength test

Test pressure	Pipe volume	Adjustment period	Min. test period	Permissible pressure drop	Min classification	Member State
100 kPa	-	-	10 min	< 1 % of test pressure	1 kPa	DE

A.3 Tightness test according to EN 1775 and national implementation for maximum operating pressure up to 100 hPa

Tested system: Pipework including valves pressure regulator, gas meter; excluding, gas appliances.

A pressure regulator or gas meter may be included, if designed for test pressure.

Test medium: Air or inert gas (e.g. N₂).

Table A.2 — National parameters for tightness test

Test pressure	Pipe volume	Adjustment period	Min. test period	Permissible pressure drop	Min classification	Member State
150 hPa	< 100 l ≥ 100 l < 200 l ≥ 200 l	10 min 30 min 60 min	10 min 30 min 60 min	< 1 % of test pressure	0,1 hPa	DE

A.4 Fitness test according to EN 1775 and national implementation for maximum operating pressure up to 100 hPa

Tested system: Pipework including valves; excluding, gas appliances.

A pressure regulator, gas meter may be included.

Test medium: Air, or inert gas (e.g. N₂) or operating gas.

Table A.3 — National parameters for fitness test

Test pressure	Pipe volume	Adjustment period	Min. test period ^d	Permissible pressure drop / leakage rate	Member State
23 hPa ^{a, b}	< 100 l	10 min ^c	5 min	< 1,0 l/h – fit for use ≥ 1,0; < 5,0 l/h – service needed ≥ 5,0 l/h – shut down	DE
	≥ 100 l < 200 l	30 min ^c	10 min		
	≥ 200 l < 300	60 min ^c	15 min		
	≥ 300 l < 400	120 min	20 min		
	≥ 400 l < 500	240 min	25 min		

^a Operating pressure (OP) of pipework. Supply pressure at the point of delivery according to member states communication of the gas supply conditions, as described in EU 426/2016, Annex 2.

^b If the test is carried out with other test pressure, the result has to be converted to reference conditions at 23 hPa with reference temperature 20 °C. For operating pressures > 30 mbar, the determined operating pressure shall be used as the reference operating pressure.

^c The adjustment time can be shortened if the following stability criteria are observed over a period of 2 min during the adjustment time: Pressure fluctuations 0,5 mbar; Leakage rate fluctuations < 0,2 l/h.

^d The following stability criteria shall be met during the measurement period: fluctuations of the pressure drop < 0,5 mbar or fluctuations in the leakage rate < 0,2 l/h.

A change of < 1 % on an electronic gauge can be seen as no discernible pressure drop.

A.5 Tightness test according to EN 1775 and national implementation for maximum operating pressure up to 100 hPa

Tested system: Pipework including valves, excluding pressure regulator, gas meter, gas appliances.

Connections to gas carrying pipes are not allowed.

Table A.4 — National parameters for combined strength and fitness test

Test pressure	Pipe volume	Adjustment period	Min. test period	Permissible pressure drop	Min classification	Member State
300 kPa	Up to 2 000 l ^a	2 h	2 h	< 1 % of test pressure ^b	10 kPa	DE

^a If the pipe volume exceeds 2 000 l, the test duration shall be extended by 15 min for each additional 100 l.

^b Taking into account possible temperature variation during the test period.

Annex B
(informative)

**National situations for strength test, tightness test and fitness test of gas
pipework with reference to IGEM/UP/1B**

Tightness testing and direct purging of small Liquefied Petroleum Gas/Air, Natural Gas and Liquefied Petroleum Gas installations.

Annex C (normative)

Standard methods for determining measuring uncertainty

C.1 Determination of the analytic function

The analytic function between the reference measuring method (y_j) and the test specimen (X_j) shall be determined from 50 pairs of variables, as described in the ISO/IEC Guide 98-3:2008, Appendix H.3. The measuring apparatus shall meet the requirements on uncertainty over the entire indication range.

C.2 Determination of reproducibility

The standard deviation between two measuring devices, when measuring an unknown quantity of the subject of the test, shall be determined using double determinations. The concentrations of the subject of the test shall be displayed on two identical measuring devices simultaneously.

The standard deviation S_D shall be calculated in accordance with the following formula:

$$S_D = \pm \sqrt{\frac{\sum_{i=1}^n (x_{1i} - x_{2i})^2}{2n}} \quad (\text{C.1})$$

where

$x_{1,2}$ measured values;
 n number of double determinations.

The multiplication of the standard deviation with the factor $t = 1,98$ for $2n \geq 100$ produces the uncertainty range U with a statistical certainty of 95 %, from which the reproducibility R is calculated using the following formulae:

$$U = t \times S_D \quad (\text{C.2})$$

$$R = \frac{x_{\max}}{U} = \frac{x_{\max}}{t \times S_D} \quad (\text{C.3})$$

where

x_{\max} is the upper limit of measuring range.