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Deutscher Kalibrierdienst (DKD) – German Calibration Service

Since its foundation in 1977, the German Calibration Service has brought together calibration laboratories of industrial enterprises, research institutes, technical authorities, inspection and testing institutes. On 3rd May 2011, the German Calibration Service was reestablished as a *technical body* of PTB and accredited laboratories.

This body is known as *Deutscher Kalibrierdienst* (DKD for short) and is under the direction of PTB. The guidelines and guides developed by DKD represent the state of the art in the respective areas of technical expertise and can be used by the *Deutsche Akkreditierungsstelle GmbH* (the German accreditation body – DAkkS) for the accreditation of calibration laboratories.

The accredited calibration laboratories are now accredited and supervised by DAkkS as legal successor to the DKD. They carry out calibrations of measuring instruments and measuring standards for the measurands and measuring ranges defined during accreditation. The calibration certificates issued by these laboratories prove the traceability to national standards as required by the family of standards DIN EN ISO 9000 and DIN EN ISO/IEC 17025.

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Foreword

DKD guidelines are application documents that meet the requirements of DIN EN ISO/IEC 17025. The guidelines contain a description of technical, process-related, and organizational procedures used by accredited calibration laboratories as a model for defining internal processes and regulations. DKD guidelines may become an essential component of the quality management manuals of calibration laboratories. The implementation of the guidelines promotes equal treatment of the equipment to be calibrated in the various calibration laboratories and improves the continuity and verifiability of the work of the calibration laboratories. In addition, the implementation of the guidelines allows the state of the art in the respective field to be incorporated into laboratory practice.

The DKD guidelines should not impede the further development of calibration procedures and processes. Deviations from guidelines as well as new procedures are permitted in agreement with the accreditation body if there are technical reasons to support this action.

Calibrations by accredited laboratories provide the user with the security of reliable measuring results, increase the confidence of customers, enhance competitiveness in the national and international markets, and serve as metrological basis for the inspection of measuring and test equipment within the framework of quality assurance measures.

This guideline has been drawn up by DKD's Technical Committee *Temperature and Humidity* and approved by the Board of the DKD.

This edition replaces all previous editions of DKD-R 5-7.

From 1 January 2028, only the present edition may be used.

Table of contents

1 Purpose and scope of application 7
2 Definitions 7
3 Symbols 9
3.1 Variables 9
3.2 Indices....12
4 Aim of the calibration 13
5 Requirements regarding the climatic chamber (calibration capability)....14
6 Calibration methods 16
7 Calibration procedure 18
7.1 Arrangement of the measuring locations 18
7.1.1 Calibration for useful volumes according to method (A) or (B)....18
7.1.2 Calibration for measuring locations according to method (C)....19
7.1.3 Calibration of the useful volume according to method (D) 19
7.2 Determination of the spatial temperature inhomogeneity 21
7.3 Determination of the temperature instability over time 21
7.4 Determining the influence of radiation 22
7.5 Determination of the loading influence 24
7.5.1 Active loading with power dissipation 25
7.6 Relative humidity 25
7.6.1 Inhomogeneity of the humidity....26
7.6.2 Humidity instability 27
7.7 Number of calibration points 27
8 Uncertainty contributions 28
8.1 Spatial inhomogeneity $\delta Tinhom$; $\delta Uinhom$ 28
8.2 Temporal instability $\delta Tinstab$; $\delta Uinstab$ 29
8.3 Radiation influence $\delta T\mathrm{radiation}$ 29
8.4 Loading influence $\delta Tload$; $\delta Uload$ 30
8.5 Influence of the ambient conditions $\delta Tenv$; $\delta Uenv$ 30
8.6 Resolution of the indication deviation $\delta Tres,X$; $\delta Ures,X$ 30
8.7 Measurement error of the standard measuring device δTS ; δUS 31
9 Ambient conditions 31
10 Calibration certificate 32
11 Bibliography 34
Appendix A Measurement uncertainty budgets (Example) 36
Appendix B1 Example of a certificate for calibrations according to method (A) or (B) (Variant 1) 58

Appendix B2 Example of a certificate for calibrations according to method (A) or (B) (Variant 2) 60

Appendix B3 Example of a certificate for calibration according to method (D) 62

Appendix C Example of a calibration certificate for calibration of a measuring location according to method (C) 64

Appendix D Supplement to the calibration certificate for climatic chambers 66

Appendix E Additional information for the use of climatic chambers in the context of metrological traceability 67

1 Purpose and scope of application

This guideline lays down the minimum requirements for the calibration procedure and the determination of the measurement uncertainty in the calibration of climatic chambers.

It is applicable to the calibration of climatic chambers for gas temperature and relative gas humidity or only for gas temperature.

In the context of this guideline, gas humidity is understood to mean gaseous material systems consisting exclusively of the components water and carrier gas.
The scope of the guideline covers the carrier gases air and nitrogen. For other carrier gases proof of validation is required.

This guideline also applies to the calibration of individual measuring locations in climatic chambers; in this case, the calibration is not valid for the entire climatic chamber.

In the case of a dated reference in the normative text, the reference always refers to the referenced edition of the standard.

2 Definitions

Climatic chamber

A technical facility that can be used to realise specifically selected values of the gas temperature T and, if applicable, the relative humidity U in a closed volume in a working range is referred to as climatic chamber.

Technical means (thermal insulation, air circulation, radiation shields, etc.) are used to minimise the temporal instability and spatial inhomogeneity of gas temperature and humidity as well as the deviations of the gas temperatures and humidities prevailing in the useful volume from the nominal values or, respectively, the values measured by the associated measuring systems.

Within the scope of this guideline, climatic chambers have a useful volume spanned by the measuring locations, the ratio between the largest and smallest spatial extensions of this useful volume being smaller than 5.

Climatic chambers may be either mobile or stationary. The walls serving for thermal insulation from the environment must not, however, be direct parts of buildings or vehicles but it must be possible to clearly assign them to the climatic chamber.

Calibration according to this guideline can be carried out with respect to gas temperature and relative humidity or only with respect to gas temperature (temperature chamber).

The manufacturer’s designations for a climatic chamber according to this guideline may vary, (e.g. climate cabinet, heating cabinet, deep-freeze cabinet, etc.); essential for the classification as a climatic chamber is compliance with the requirements according to Chapter 5.

Measuring location

A measuring location is the spatial position in which a temperature or humidity sensor is arranged in the useful volume for calibration.

A measuring location thus is a small volume defined by the dimensions of the sensor elements and their positioning accuracy (i.e. maximum extension in each dimension approx. 5 cm). If the measurements are carried out in one location only, the calibration result is valid for this location only. Extrapolation to a larger volume is not admissible.

Interior volume

The interior volume is defined by the interior space accessible to the user.

Useful volume

The useful volume is the part of the interior volume spanned by the measuring locations of the sensors used for calibration. Depending on the arrangement of the measuring locations, the useful volume can considerably differ from the interior volume of the climatic chamber. As a matter of principle, the calibration of the climatic chamber only applies to this useful volume. The minimum requirements regarding the position of the measuring locations in accordance with this guideline must be met (see Chapters 5 and 7.1).

If the calibration is carried out only in individual isolated measuring locations which do not span a volume, only the locations but not the chamber and its interior volume are considered to be calibrated [see calibration method (C)].

Calibration method (D) is a special case. If the required positioning of the sensors is observed (see Section 7.1.3), the entire useful volume is also considered calibrated.

Reference measuring location

The reference measuring location is the position in the useful volume for which the difference between the gas temperature and gas humidity and the indicated values is stated.

Preferably, the geometrical centre of the useful volume is selected as reference measuring location.

Other definitions of the reference measuring location are also possible at customer's request. The position of the reference measuring location must be stated in the calibration certificate.

Atmospheric pressure

In this guideline, "atmospheric pressure" refers to the pressure range from 50 hPa below to 50 hPa above the ambient pressure which has not been altered by technical measures.

Gas temperature / gas humidity

The gas temperature is the temperature of the gas mixture in the useful volume of the climatic chamber; the gas humidity is the relative humidity of the gas mixture. This guideline considers the gas mixtures air/water and nitrogen/water. The gas mixture air/water is often also referred to as air temperature / air humidity.

3 Symbols

3.1 Variables

Table 1: Overview of the variables used

Variable	Description	Unit
T or t	Gas temperature	K or °C
T_d or t_d	Dew point temperature	K or °C
T_f or t_f	Frost point temperature	K or °C
U [1]	Relative humidity	1 [2]
δT_{inhom}	Spatial inhomogeneity of the gas temperature	K
δU_{inhom}	Spatial inhomogeneity of the relative humidity	1 Fehler! Verweisquelle konnte nicht gefunden werden.
T_{ref} / $T_{\text{ref, load}}$ or t_{ref} / $t_{\text{ref, load}}$	Gas temperature of the reference location (unloaded / loaded)	K or °C
U_{ref} / $U_{\text{ref, load}}$	Relative humidity of the reference location (unloaded / loaded)	1 Fehler! Verweisquelle konnte nicht gefunden werden.
δT_{instab}	Temporal instability of the gas temperature	K
δU_{instab}	Temporal instability of the relative humidity	1 Fehler! Verweisquelle konnte nicht gefunden werden.
$\bar{T}$ or $\bar{t}$	Mean gas temperature over time	K or °C
$\bar{U}$	Mean relative humidity over time	1 Fehler! Verweisquelle konnte nicht gefunden werden.
$\delta T_{\text{radiation}}$	Radiation influence on the gas temperature	K
T_{le} or t_{le}	Temperature of a body with low emissivity	K or °C
T_{he} or t_{he}	Temperature of a body with high emissivity	K or °C
T_{wall} or t_{wall}	Wall temperature	K or °C

[1] The variable U of the relative humidity must not be confused with the variable U of the expanded measurement uncertainty. The meaning of the variable used must be checked in each individual case.
[2] The relative humidity is a dimensionless ratio that is usually expressed as a percentage (%). Further prefixes or suffixes (e.g. % rh or % RH) are not mandatory but can be used for clarification.

Variable	Description	Unit
δT_{load}	Loading influence on the gas temperature	K
δU_{load}	Loading influence on the relative humidity	1 Fehler! Verweisquelle konnte nicht gefunden werden.
δT_{env}	Environmental influence on the gas temperature	K
δU_{env}	Environmental influence on the relative humidity	1 Fehler! Verweisquelle konnte nicht gefunden werden.
$\delta T_{\text{res,std}}$ / δT_{res}	Resolution of the standard thermometer / temperature indication of the climatic chamber	K
$\delta U_{\text{res,std}}$ / δU_{res}	Resolution of the standard hygrometer / humidity indication of the climatic chamber	1 [3]
$\delta T_{i,\text{ std}}$	Measurement error of the standard thermometer at measuring point i (i = 1, ..., N)	K
$\delta U_{i\text{ ,std}}$	Measurement error of the standard hygrometer at measuring point i (i = 1, ..., N)	1 [3]
δT_{cal}	Measurement error of the standard thermometer according to its calibration	K
δU_{cal}	Measurement error of the standard hygrometer according to its calibration	1 [3]
δT_{drift}	Drift of the standard thermometer over the recalibration period	K
δU_{drift}	Drift of the standard hygrometer over the recalibration period	1 [3]
δT_{heat}	Measurement error of the standard thermometer due to self-heating	K
$T_{\text{ind,S}}$ or $t_{\text{ind,S}}$	Indication of the standard thermometer	K or °C
$U_{\text{ind,S}}$	Indication of the standard hygrometer	1 [3]
ΔT_{X}	Deviation of the gas temperature for the climatic chamber	K
ΔU_{X}	Deviation of the relative humidity for the climatic chamber	1 [3]
$T_{\text{ind,X}}$ or $t_{\text{ind,X}}$	Indication of the gas temperature in the climatic chamber	K or °C
$U_{\text{ind,X}}$	Indication of the relative humidity in the climatic chamber	1 [3]

[3] The relative humidity is a dimensionless ratio that is usually expressed as a percentage (%). Further prefixes or suffixes (e.g. % rh or % RH) are not mandatory but can be used for clarification.

Variable	Description	Unit
T_i or t_i	Measured value of the gas temperature for measuring location i in the climatic chamber	K or °C
U_i	Measured value of the relative humidity for measuring location i in the climatic chamber	1 [3]
L	Edge length of the interior space	m
x	Wall distance	m

3.2 Indices

Table 2: Overview of the indices used

Indices	Designation
d	Dew point
f	Frost point
inhom	Inhomogeneity
instab	Instability
ref	Reference location
load	Loaded
radiation	Radiation influence
le	Low emissivity
he	High emissivity
env	Environment
res	Resolution
std	Standard
cal	Calibration
heat	Self-heating
ind	Indication
i	Measuring location i

4 Aim of the calibration

The calibration of a climatic chamber serves to determine the deviation[4] of the values of the climatological characteristics *gas temperature* and *relative humidity* displayed by the indicator of the climatic chamber for those parts of the interior volume intended for use or for individual measuring locations of the interior volume. Besides these deviations, additional properties such as inhomogeneities, stabilities etc. are determined to characterise the climatic chamber as well as potential effects on the test material placed in the climatic chamber. These results on the one hand are of great interest to the user of the climatic chamber as they describe its properties during use and on the other hand are necessary to determine the measurement uncertainty of the calibration results.
The objectives thus are the following:

- Calibration of the indication for temperature and relative humidity by comparison with the values for gas temperature and gas humidity as measured in the useful volume using reference devices (statement of deviations or corrections, respectively)

- Determination of the uncertainty of temperature and relative humidity during calibration under defined conditions

- At the customer's request, the calibration can include a test for compliance with user tolerances under defined conditions and/or technical specifications.

- At the customer's request, calibration can also be carried out in individual measuring locations only. In this case, however, some uncertainty components will not be determined and not be taken into account. The result then will be valid only for these locations but not for the entire chamber. [→ calibration method (C)]

The calibration does not provide complete information about the climatological quantities (temperature and relative humidity) at the surface or even in the interior volume of test loads placed in the climatic chamber. The determination of the body temperature or material humidity of the test load requires the use of calibrated thermometers or hygrometers in the test load.

[4] As an alternative to the deviation between the indicated value and the reference value (standard), it is also possible to state the necessary correction for the indication. This differs in its value from the deviation only by the sign.

5 Requirements regarding the climatic chamber (calibration capability)

In accordance with this Guideline, climatic chambers can only be calibrated if they fulfil the following requirements:

- Availability of sensors for gas temperature and, if necessary, also for gas humidity with the associated indicators as components of the climatic chamber.
- Availability of control systems for the quantities to be calibrated (relative humidity and/or temperature) as components of the climatic chamber; a temperature control must be present in all cases.
- Atmospheric pressure in the interior (ambient pressure ± 50 hPa)
- The system works with humid air or nitrogen.
  In case of pure temperature measurements, other gases are also permitted as long as they do not influence the temperature measurement. Solid or liquid additives (such as salts) are generally excluded. Calibration capability for gas humidity according to this guideline is only given for humid air or nitrogen (see Chapter 1).
- Information regarding heat sources and heat sinks in the interior volume must be available. Direct radiation sources (e.g. radiators for sun simulation or similar) are excluded.

In addition, availability of technical documentation can be of advantage, but is not a requirement. In particular, information on the manufacturer's specifications and on the type and position of the sensors, the properties of the insulation and the design of the temperature control and humidification can be helpful for evaluating the calibration results.
As to the maximum working and calibration ranges, this Guideline distinguishes between climatic chambers with active air circulation and climatic chambers without active air circulation (forced convection) in the interior. In both cases, the climatic chamber must have active heating and/or cooling.

a) Climatic chambers with gas / air circulation systems:

- The air circulation system must be an integral part of the calibration item and ensure metrologically appropriate air circulation.
  For variable setting of the circulation rate, the minimum requirement according to the manufacturer's specification is to be observed. The setting of the circulation rate, if variable, is to be stated in the calibration certificate (e.g. rotational speed).

- A prerequisite for the calibration of the relative humidity according to methods (A), (B) and (D) is that the gas/air flow rate ensures the circulation of the entire gas/air volume within max. 30 s. For verification, the manufacturer's specification will be sufficient.
  If the calibration item has an air circulation system but does not fulfil the above-mentioned criterion for the gas/air flow rate, only calibration according to method (C) is permitted without restriction. Methods (A), (B) and (D) may only be used with procedure (F3) according to chapter 7.6.

- The maximum gas temperature range extends from -180 °C to 500 °C if the criterion for the gas/air exchange rate is met. Otherwise, the gas temperature range is limited to -160 °C to 350 °C (see Table 3). From a technical and physical point of view, calibrations for relative humidity are only possible and reasonable in corresponding partial ranges.

b) Climatic chambers without gas/air circulation systems:

- The maximum gas temperature range is -160 °C to 350 °C.
- The maximum useful volume is limited to 2000 ℓ.
- Calibration of the quantity *relative humidity* is not admissible.
- Active loading with power dissipation is not admissible.

Table 3 shows an overview of the calibration options depending on the gas / air circulation in the test chamber volume.

Table 3: Overview of calibration options depending on the gas / air circulation

Restrictions related to:	**Air circulation system available:**		
	yes		no
	The calibration item circulates the gas/air in the test chamber volume at least once within **30 seconds.**	The calibration item cannot circulate the gas/air of the test chamber volume at least once within **30 seconds.**	natural convection
Useful volume (Chapter 5)	not limited	not limited	max. 2000 litres
Temperature range (Chapter 5)	-180°C to 500°C	-160°C to 350°C	-160°C to 350°C
Calibration methods (Chapter 6)	all methods admissible	**Calibration of the temperature:** all methods admissible **Calibration of the humidity:** method (C) admissible without restriction; methods (A), (B), (D) only according to procedure (F3) (Chapter 7.6)	**Calibration of the temperature:** all methods admissible **Calibration of the humidity:** not admissible
Humidity measurement procedure (Chapter 7.6)	all methods admissible	Only procedure 3 admissible for methods A, B and D Method C: all procedures admissible	**Calibration of the humidity:** not admissible
Active loading (Section 7.5.1)	max. 10 % of the heating/cooling capacity of the calibration item	max. 10 % of the heating/cooling capacity of the calibration item	not admissible

6 Calibration methods

There are four essentially different methods that can be used to calibrate a climatic chamber (the measurements always refer to gas temperature and relative humidity):

(A) Calibration is carried out for the useful volume spanned by the measuring locations in the unloaded chamber. As to the number of measuring locations, the minimum requirements apply (see chapter 7.1).
The calibration includes:
- determination of the indication deviation between the indication and the reference measuring location in the unloaded state,
- determination of the spatial inhomogeneity in the empty useful volume,
- determination of the temporal instability in the empty useful volume,
- determination of the radiation influence for the reference measuring location,
- on customer request, determination of the loading influence in the reference measuring location by comparison of loaded and empty useful volume.

(B) Calibration is performed for the useful volume spanned by the measuring locations in the loaded chamber. The loading can be realised according to the user's typical application or by filling at least 40 % of the useful volume with test bodies. For the individual investigations and uncertainty components, the regulations for method (A) apply. The influence of the loading itself is determined by an additional measurement in a central measuring location in the unloaded state.
The calibration includes:
- determination of the indication deviation between indication and reference measuring location, each in the loaded state,
- determination of the spatial inhomogeneity in the loaded useful volume,
- determination of the temporal instability in the loaded useful volume,
- the determination of the radiation influence in the reference measuring location,
- determination of the loading influence[5] in the reference measuring location by comparison of loaded and empty useful volume at all calibration points.

[5] Note: Optionally, the determination of the loading influence can be omitted. In this case, the calibration certificate must indicate that the influence of the load is not included in the measurement uncertainty.

(C) Calibration is carried out for individual measuring locations in the climatic chamber which **do not** span a useful volume.
The calibration includes:

- determination of the indication deviation between measurement in the measuring location and indication in both loaded and unloaded state,
- determination of the local spatial inhomogeneity in the measurement location,
- determination of the temporal instability in the measurement location,
- determination of the radiation influence in the measurement location,
- on customer request, determination of the loading influence in the measuring location by comparing loaded and empty useful volume.

(D) Calibration is carried out for the useful volume of very small unloaded climatic chambers (interior volume up to 70 ℓ) by arranging three temperature sensors diagonally. The spatial centre forms the reference measuring location.
The calibration includes:

- determination of the indication deviation between indication and reference measuring location in the unloaded state,
- determination of the spatial inhomogeneity in the empty useful volume,
- determination of the temporal instability in the empty useful volume,
- determination of the radiation influence for the reference measuring location,
- on customer request, determination of the loading influence for the reference measuring location by comparing loaded and empty useful volume.

7 Calibration procedure

7.1 Arrangement of the measuring locations

7.1.1 Calibration for useful volumes according to method (A) or (B)

For calibrations according to methods (A) and (B), measurements are to be carried out in several locations in the useful volume.

Up to a useful volume of 2000 ℓ, the specifications regarding the number and spatial position of the measuring points are to be made in accordance with DIN EN 60068, Part 3-5 [2], i.e. the measuring locations form the corner points and the spatial centre of a cuboid which spans the useful volume (9 measuring locations).

For useful volumes > 2000 ℓ, the surface of the useful volume must additionally be covered by a virtual measuring grid, i.e. the measuring points are to be arranged in the useful volume in the form of a cubic lattice with a maximum distance of 1 m between the measuring points.

At the customer's request, other positions are also possible. However, it must be ensured that the useful volume is enclosed by the volume spanned by the measuring points, that the maximum spacing between neighbouring measuring locations does not exceed 1 m and that the spatial extreme values of the climatological quantities for the useful volume are determined (all conditions must be fulfilled simultaneously) The choice of alternative measuring locations, e.g. in analogy to DIN 12880 [6], is possible if they are described in the calibration certificate and the stated conditions are complied with as minimum requirements.

The calibration result is valid only for the volume spanned by the measuring points. Spatial interpolation of the measured values is permitted only for the useful volume enclosed by the measuring points.

The stated measurement uncertainty, with reference to the reference measuring point, applies to the entire useful volume. Interpolation of the uncertainty contributions is not permitted. Extrapolation of the measurement results beyond the volume spanned by the measuring locations is not permitted.

The dimensions of the interior volume of the climatic chamber and the selected position of the measuring locations must be given in the calibration certificate in form of a sketch.

To define the wall distance x as a function of the edge length L of the interior volume, Table 4 applies based on the specifications of DIN EN 60068, Part 3-5 [2] or DIN 12880 [6].

Table 4: Practical dimensions for the interior volume

Size	Interior volume in ℓ	Recommended wall distance x	Minimum wall distance x_{min} in mm
I.	up to 1000	$L/10$	50
II.	> 1000 to 2000	$L/10$	100
III.	> 2000	$L/10$	150
Note: Not all climatic chambers have a cubic shape (interior volume / useful volume). Arrangements in accordance with DIN 12880 [6] can reduce the minimum distance to the wall.			

7.1.2 Calibration for measuring locations according to method (C)

Calibrations limited to individual locations within the useful volume [method (C)] are only admissible at the specific request of the customer. In this case, the calibration result is valid only for the measuring locations investigated. This must be stated in the calibration certificate. As calibration item **"measuring location(s) in the climatic chamber"** is to be stated in the certificate. The contribution of the local spatial inhomogeneity in the measuring locations must be determined for each measuring location using two thermometers arranged with a spacing of approx. 2 cm to 5 cm. A minimum distance corresponding to the active sensor length must be maintained. One of these thermometers is arranged in the position defined for the statement of the calibration result (measuring location) and the other one at the necessary distance. The measurement result of this thermometer is only used to determine the local spatial inhomogeneity and does not explicitly enter into the calibration result.

If the emissivity of the two thermometers is significantly different, this measurement can also serve to determine the influence of radiation.

However, the difference determined between the two thermometers is used in full for the local inhomogeneity. This contribution therefore contains additional radiation influences.

The calibration certificate must clearly state that the difference determined between the two thermometers includes both the contribution of the local inhomogeneity and the influence of radiation.

Eliminating the influence of radiation on the determination of local inhomogeneity in the measuring location requires the use of two identical thermometers with low emissivity, arranged 2 cm to 5 cm from each other, and a third thermometer with high emissivity at the measuring location[6].

When calibrating more than one measuring location according to method (C) (without spanning a useful volume), the use of two thermometers in one measuring location can be dispensed with if the uncertainty contribution due to the local inhomogeneity and the positioning accuracy can be adequately estimated from the difference of the thermometers for the individual measuring locations. The procedure is to be described in the calibration certificate.

The dimensions of the interior volume of the climatic chamber and the position selected for the measuring points must be indicated the calibration certificate in form of a sketch.

7.1.3 Calibration of the useful volume according to method (D)

As a rule, calibrations of the useful volume are carried out according to method (A) or (B).
In the case of very small internal volumes (up to 70 ℓ), a loaded state may already occur depending on the dimensions of the standards used. This means that a calibration according to method (A) and thus a statement about the unloaded state of the calibration item would not be possible.
In this case, method (D) is therefore admissible as an alternative to method (A).
For interior volumes > 70 ℓ, method (D) is excluded.
When using method (D), at least 3 measuring locations are selected. These are to be arranged spatially diagonally (body diagonal) in the useful volume.

At least two corner points and the intersection point of the body diagonal must be selected.
Further points on the body diagonal can be optionally selected.

[6] Note: The measurement uncertainty contribution is potentially greater when measuring with only two thermometers, but the effort involved is less than with the method using three thermometers.

Here, it should be noted that in the case of non-cubic rooms, the maximum length is to be selected.

The useful volume for method (D) is obtained by parallel displacement of the interior surfaces of the climatic chamber through the corner points of the body diagonal.
The spatial centre forms the reference measuring location. In addition, a sensor is to be positioned in the reference measuring location to determine the influence of radiation.
For illustration purposes, a sketch of the arrangement of the sensor positions must be included in the calibration certificate.

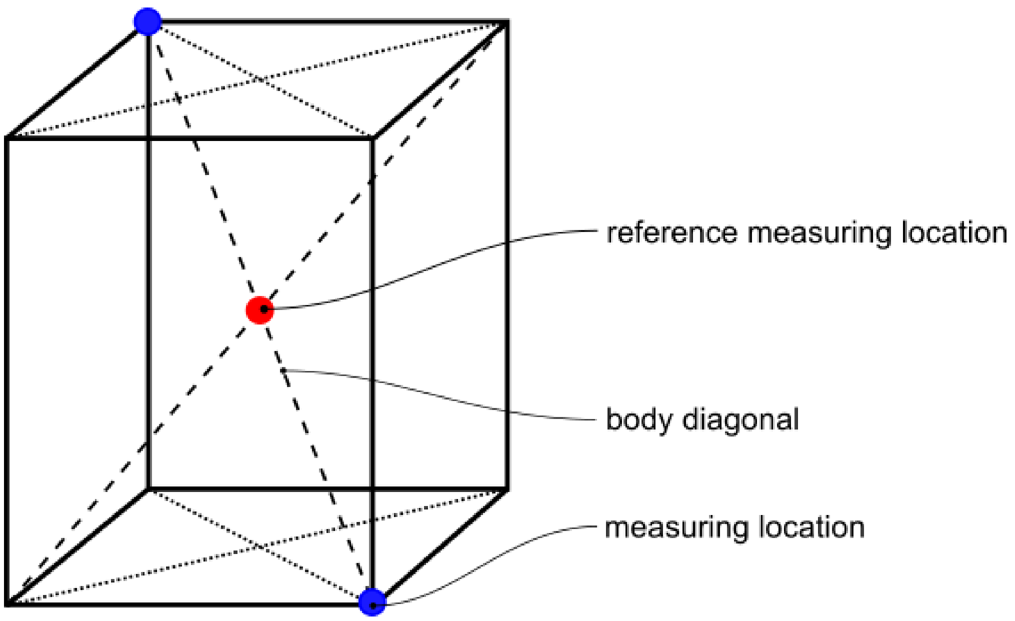

Figure 1: Example of the arrangement of the sensor positions (view of the useful volume calculation)

In contrast to method (C) of this Guideline, the calibration according to method (D) is valid for the entire useful volume.
The recommended minimum wall distances x when using method (D) are given in Table 5.

Table 5: Practical dimensions for the interior volume and the useful volume

Interior volume in ℓ	Recommended wall distance x	Minimum wall distance $x_{\min}$ in mm
up to 70	$L/10$	30 [7]
Note: Not all climate chambers have a cubic shape (interior volume / usable volume). Arrangements in accordance with DIN 12880 [6] can reduce the minimum distance to the wall.		

[7] Measurements in the boundary layer are to be avoided.

7.2 Determination of the spatial temperature inhomogeneity

The spatial inhomogeneity of the gas temperature is determined as the maximum deviation of the temperature of a corner or wall measuring location according to DIN EN 60068-3-5 [2] from the reference measuring location (in most cases in the centre of the useful volume).

The spatial inhomogeneity must be determined for all calibration temperatures. The spatial inhomogeneity is investigated only in calibrations for a useful volume according to method (A), (B) or (D) (see Sections 7.1.1 and 7.1.3).

In calibrations according to method (C), only the local inhomogeneity is determined to estimate the uncertainty contribution due to inhomogeneity (see Section 7.1.2).

7.3 Determination of the temperature instability over time

The temporal instability for the gas temperature is determined from the registration of the temporal course of the temperature over a period of at least 30 min after the equalised state has been reached.

An equalised state is considered to have been reached when no further systematic variations in temperature can be measured. Depending on the calibration temperature, interior volume, difference between the calibration points, ambient conditions, gas/air velocities, etc., the waiting time can vary greatly.

Temperature equalisation is significantly impaired without gas/air circulation. The resulting longer equalisation times must be taken into account. The measurements may only be carried out 30 min after the equalised state has been reached, i.e. when the temperatures at all measuring points no longer show any systematic changes for at least 30 min.

The remaining temporal changes must not exceed the specified temporal instability taken into account in the measurement uncertainty.

To measure the temperature instability over time, at least 30 measurement values are to be recorded in 30 min at more or less constant time intervals.

The measurement needs to be performed at least for the reference measuring location and for each calibration temperature.

The temporal instability is to be investigated for all calibration methods.

7.4 Determining the influence of radiation

At gas temperatures in the climatic chamber differing from ambient temperature, the inner wall of the climate chamber will always have a temperature that deviates from the gas temperature. Under these conditions, however, bodies in the useful volume do not achieve the gas temperature due to heat exchange by radiation. This is valid both for the user's loads and for the thermometers used for calibration.

The difference between the gas temperature to be determined and the temperature of a thermometer depends on the emissivity of the thermometer surface, geometry/dimensions and position of the sensor, the gas/air speed at the sensor, and on the difference between gas, air and wall temperature.

The influence of radiation increases with increasing difference between gas and wall temperature. In addition, this influence increases more than proportionally to the absolute temperature.

At the customer's request, the influence of radiation on the deviation of the temperature of a body from the gas temperature can also be determined using a test body typical of the customer. In this case, the gas temperature is measured with a thermometer with low emissivity or radiation shield, and the body temperature is measured with a thermometer which is introduced into the test body. This method then replaces the determination of the influence of radiation. It must be described in the calibration certificate and restricts the result to these typical conditions. This method is most suitable for customers who always store similar bodies in the useful volume.

The influence of radiation can be estimated using one of the following 3 procedures:

(S1) The influence of radiation can be determined by measuring the temperature in the reference measuring location using two thermometers with different emissivity ε. One of the thermometers should have as high an emissivity as possible (i.e. $\varepsilon > 0.6$), the other as low an emissivity as possible (i.e. $\varepsilon < 0.15$).

The emissivity of both thermometer surfaces must be known with sufficient accuracy. The difference between the two thermometers is a measure of the influence of radiation if wall temperature and gas temperature are not identical. The thermometer with low emissivity approximately indicates the gas temperature. The gas temperature is obtained by extrapolation to the emissivity $\varepsilon = 0$.

The additional sensor with high emissivity used to determine the influence of radiation should be cylindrical, at least 20 mm long and have a minimum diameter of 4 mm. The diameter can also be realised with thermally conductive sleeves.

A high emissivity can be realised, for example, with a PTFE surface or blackened surfaces. A low emissivity of the standard thermometer can be realised, for example, by reflective coatings such as polished nickel or gold. Other realisations are possible.

Oxidation or roughness of the surface must be avoided, especially for the realisation of the low emissivity.

(S2) The gas temperature can also be measured with a thermometer that is protected from the influence of the wall by a radiation shield. This radiation shield must be ventilated or, by its arrangement and design, must allow the thermometer to be adequately exposed to the circulated air.

The thermometer with the radiation shield is used to approximately measure the gas temperature. A second thermometer with high emissivity is used to determine the temperature under the influence of radiation.

The difference ascertained between the two measurements is a measure of the radiation influence if the wall temperature deviates from the gas temperature.

(S3) For temperatures from 0 °C to 50 °C, the metrological determination of the radiation influence can be omitted. In this case, a maximum contribution to the measurement uncertainty of 0.3 K can be assumed for the influence of radiation. Should the difference between ambient temperature and gas temperature (in the climatic chamber) during calibration exceed 30 K, the radiation influence is in any case to be determined according to (S1) or (S2)[8].

Procedures (S1) and (S2) are aimed at measuring the real gas temperature as reliably as possible. They do not serve to estimate the influence of radiation on the temperature of a body in the useful volume.

Procedure (S3) provides an estimate of the influence of radiation on the measurement uncertainty under the above conditions.

The influence of radiation must be taken into account for calibration methods (A) to (D).

The measurements with the smallest emissivity ($\varepsilon < 0.15$) are stated as result. A correction of the measurement results for the radiation influence ($\varepsilon = 0$) is not made. However, this would be possible if requested by the customer (to be noted in the calibration certificate).

[8] Note: Procedure (S3) is based only on an estimate of the radiation influence as a contribution to the measurement uncertainty which is, however, only admissible if the stated conditions are met. At the expense of a potentially greater estimation of the associated measurement uncertainty, the amount of work involved is reduced.

7.5 Determination of the loading influence

Climatic chambers are usually calibrated without a load [Method (A)]. At the customer's request, calibration can be carried out with a specific load [Method (B)]. This load is to be described in the calibration certificate and the result is only valid for these particular conditions. This procedure is particularly useful if the customer always operates the calibration item with similar load and if this arrangement differs significantly from an empty useful volume (empty chamber).

Especially for climatic chambers without forced circulation, the spatial distribution of the temperature can be strongly influenced by the load. In this case, the loading influence on the reference measuring location should therefore be investigated for all calibration temperatures.

For this purpose, loading can be carried out in a manner typical for the user or with test bodies. The loading should simulate the maximum impairment of the spatial temperature equalisation. It is to be described in the calibration certificate.

Without specific information/requirements from the customer, the loading comprises at least 40 % of the useful volume. The influence of loading on the spatial homogeneity should be determined by measurements in the unloaded and loaded state for at least one measuring location.

Should the reference measuring location not be accessible due to the loading, the reference measuring location for both measurements (loaded and unloaded) is to be moved accordingly.

For calibrations according to method (B), the calibration result relates to the loaded state. The contribution of the load to the measurement uncertainty is taken into account. Calibration is carried out at least for the reference measuring location with and without load, and the maximum difference is recognised as half-width of a rectangular uncertainty contribution.

The loading influence can be investigated using a customer-specific load or a test load. The volume of the test load must be at least 40 % of the useful volume. The selected load is to be described in the calibration certificate.

Along with the load measurement, the following measurements are required. In this case, a prerequisite is that the reference measuring location be located in the centre of the useful volume (standard).

Calibration method	**Unloaded**		**Loaded**	
	Measuring locations	Reference measuring location	Measuring locations	Reference measuring location
(A)	**x**	☒	**-**	**(x)**
(B)	**-**	**(x)**	**x**	☒
(C)	**-**	☒	**-**	**(x)**
	-	**(x)**	**-**	☒
(D)	**x**	☒	**-**	**(x)**

☒ = Reference measurement (deviation from the indication as result in the calibration certificate)
x = Measurement (to determine measurement uncertainty contributions and additional information in the calibration certificate)
(x) = on customer request

7.5.1 Active loading with power dissipation

In case that the loading of the climatic chamber actively implements power dissipation (i.e. heat is supplied or dissipated by the load), the power dissipation within the volume of the climatic chamber must not exceed 10 % of the power needed for cooling or heating (the smallest of both values is decisive). This power must be generated almost uniformly over the useful volume; otherwise, only proportionately smaller power dissipation is admissible for smaller spatial sections (weighting of the climate control power of the climatic chamber by the ratio of the volume of the heat source to useful volume).

The influence of the power dissipation on the spatial temperature distribution must be determined within the scope of the measurement uncertainty contributions of the loading influence. This is done by determining the loading influence with and without power dissipation of the load (heat sources switched on and off). The difference determined is added to the uncertainty contribution of the load (see Chapter 8.4). For calibrations according to method (B), the load must be active during the calibration.

7.6 Relative humidity

There are three possible procedures to determine the spatial distribution of the relative humidity in the useful volume of a climatic chamber with air circulation. The selected procedure must be documented in the calibration certificate. The resulting contributions to the measurement uncertainty (depending on the selected procedure) must be determined and taken into account in the measurement uncertainty budget.

(F1) Measurement of the absolute humidity (e.g. in the form of the dew point temperature or the frost point temperature) in the reference measuring location and calculation of the spatial distribution of the relative humidity on the basis of the measured distribution of the gas temperature

(F2) Measurement of the relative humidity in the reference measuring location and calculation of the absolute humidity in the reference measuring location from the gas temperature measured in the reference measuring location and subsequent calculation of the spatial distribution of the relative humidity on the basis of the measured distribution of the gas temperature

(F3) Measurement of the relative humidity in all measuring locations in analogy to the determination of the gas temperature distribution (Chapter 7.1)

Procedures (F1) and (F2) may be used if a homogenous distribution of the absolute humidity in the useful volume can be assumed. This assumption is justified if the following conditions are met:

- The climatic chamber must provide adequate gas/air circulation. According to Chapter 5, this is achieved if the entire gas/air volume is circulated once in a maximum of 30 seconds.

- When measuring according to method (B), the loading must not have any influence on the distribution of the absolute humidity, i.e. it must be possible to rule out any influence on the absolute humidity due to condensation and/or vaporisation of water on the surface of the load.
  If the type of load (e.g. open samples) has an influence on the distribution of the absolute humidity, only procedure (F3) is admissible for calibration of the humidity. Type and quantity of the load are to be exactly specified in the calibration certificate.
- There are no active sources or sinks for water vapour in the useful volume.
- There is no gas/air exchange with the environment due to leaks.

For the measurement and the determination of the measurement uncertainty of the absolute and relative humidity in the reference measuring location in procedures (F1) and (F2), the specifications of DKD-R 5-8 [12] are to be observed.

In particular, when determining the relative humidity in the reference measuring location according to procedure (F2) using relative humidity sensors, the specification of DKD-R 5-8 [12] (Chapter 5.5) regarding the simultaneous use of two standard hygrometers must be observed.

This is not the case when using psychrometers. Here, the general notes regarding the use of psychrometers as a standard for determining the relative humidity are to be observed – DKD-R 5-8 [12] (Chapter 5.4).

In addition, when using procedure (F2), the respective contributions obtained from measurement and calculation which are stated in the uncertainty budget are to be taken into account (including uncertainty of the measurement of the relative humidity, uncertainty of the determination of the gas temperature in the reference measuring location, uncertainty of the gas pressure and conversion of relative humidity into absolute humidity).

In method (C), the relative humidity is determined either by measuring the absolute humidity and gas temperature in the measuring location in question and then calculating it, or by directly measuring the relative humidity and gas temperature in the measurement location. This corresponds to either procedure (F1) without determination of the spatial distribution or procedure (F3) applied only to the measuring location. For more than one measuring location, procedure (F2) can be applied accordingly in accordance with method (C), so the absolute humidity is only determined in one of the measuring locations under consideration. When applying procedure (F2) or (F3) to method (C), the measurement for the direct measurement of the relative humidity using relative humidity sensors in accordance with the above description must be carried out using two standard hygrometers at the measurement location under consideration.

7.6.1 Inhomogeneity of the humidity

The spatial inhomogeneity is determined as the maximum deviation of the relative humidity of a corner or wall measuring location according to DIN EN 60068-3-5 [2] from the relative humidity of the reference measuring location (in most cases in the centre of the useful volume). It is to be determined separately for all calibration points with relative humidity.

Investigation of the spatial inhomogeneity is carried out only for calibrations of a useful volume according to method (A), (B) or (D). The procedures (F1), (F2) and (F3) described above can be used for this purpose.

For calibrations according to method (C), only the local inhomogeneity is determined to estimate the inhomogeneity-related uncertainty contribution (see Section 7.1.2).

7.6.2 Humidity instability

To measure the temporal instability of the humidity, at least 30 measurement values are to be recorded at approximately constant time intervals after an equilibrium has been established for 30 minutes.

The measurement is required at least for the reference measuring location and for each climate point.

If the absolute humidity is determined only in the reference measuring location [i.e. according to procedures (F1) and (F2)], the relative humidity in the measuring location shall be determined at all times from the gas temperature in the measuring location and the gas temperature and the corresponding absolute humidity in the reference measuring location at that time.

Further investigations do not form part of this Guideline.

7.7 Number of calibration points

When calibrating a climatic chamber for a certain temperature or humidity range, calibration is required for at least three temperatures (for pure temperature calibration or for one humidity) or at least three relative humidities (for one gas temperature) of the respective range.

If the temperature difference does not exceed 20 K or if the difference in relative humidity does not exceed 50 %, the number of measuring points can be limited to the start and end value of the applicable range (at least two instead of three measuring points). The selection of the measuring points must be agreed with the customer based on the above specifications.

For example,

1) application range: 20 °C bis 60 °C and 30 % to 75 % relative humidity
   calibration points: 30 % and 75 % to 20 °C, 40 °C and 60 °C
2) application range: 20 °C bis 60 °C and 15 % to 85% relative humidity
   calibration points: 15 %, 50 %, 85 % at 20 °C, 40 °C and 60 °C
3) application range: 20 °C to 40 °C and 30 % to 75% relative humidity
   calibration points: 30 %, 75 % at 20 °C and 40 °C

Calibration for only one temperature or humidity point (set value) of the operating range of the climatic chamber is permissible at the customer's request but limits the calibration result to this operating point (± expanded measurement uncertainty).

This must be indicated in the calibration certificate.

Single-point calibrations are excluded to cover a temperature or humidity range.

8 Uncertainty contributions

The measurement uncertainty to be specified is essentially made up of the uncertainty of the measurement of temperature and relative humidity with the reference measuring devices, the uncertainties of the indicating devices of the climatic chamber, the contributions of the temporal and spatial distributions in the useful volume as well as the loading influences.
As climatic chambers serve to realise defined gas temperatures and humidities, the uncertainty assigned to the generated gas temperatures and humidities must be specified in the calibration certificate.
The temperature of the test pieces in the useful volume may significantly deviate from the gas temperature. When using the climatic chamber, the user can in most cases determine the temperature of the test pieces with smaller uncertainties a calibrated thermometer. The temperature of defined test bodies and their uncertainty can be stated at the customer's request, exactly specifying the measurement conditions and the test bodies.
Should it not be possible to determine individual influences on the calibration result and its measurement uncertainty, their maximum possible contribution to the uncertainty must be estimated and taken into account. It should then be stated in the calibration certificate that the respective influence has only been only estimated in the stated uncertainty. The basis/source for this estimate is to be stated. Spatial interpolations of the measurement uncertainty contributions are not admissible.
It must generally be pointed out that the uncertainties depend on the conditions of use. The measurement conditions for the calibration are therefore to be described as completely as possible. If the conditions of use by the customer do not vary greatly, the calibration conditions should be agreed upon before carrying out the calibration. The aim of this is to ensure that the calibration is carried out under conditions that are as close as possible to those prevailing during use by the customer.

8.1 Spatial inhomogeneity δT_{inhom} ; δU_{inhom}

The spatial inhomogeneity is determined as the maximum deviation of the relative humidity or temperature of a corner or wall measuring location from the reference measuring location (usually in the centre of the useful volume).
It is equivalent to the half-width of a rectangular contribution with an expected value of 0.

$$|\delta T_{\mathrm{inhom}}| \leq \max |T_{\mathrm{ref}} - T_{\mathrm{i}}| \tag{1}$$

$$|\delta U_{\mathrm{inhom}}| \leq \max |U_{\mathrm{ref}} - U_{\mathrm{i}}| \tag{2}$$

The following results for the associated standard uncertainties:

$$u(\delta T_{\mathrm{inhom}}) = \frac{1}{\sqrt{3}} \cdot \max |T_{\mathrm{ref}} - T_{\mathrm{i}}| \tag{3}$$

$$u(\delta U_{\mathrm{inhom}}) = \frac{1}{\sqrt{3}} \cdot \max |U_{\mathrm{ref}} - U_{\mathrm{i}}| \tag{4}$$

The spatial inhomogeneity is to be taken into account for calibration methods (A) to (D) and for all calibration temperatures and humidities. In methods (A), (B) and (D) it is valid for each point of the entire useful volume and in method (C) only for the respective measuring locations. The results for $\delta T_{\mathrm{inhom}}$ and $\delta U_{\mathrm{inhom}}$ are stated in the calibration certificate (see Appendix B and C).

8.2 Temporal instability δT_{instab} ; δU_{instab}

The temporal instability is determined in the reference measuring location by recording the temporal course (variations) of temperature or relative humidity over a period of at least 30 minutes after equalised conditions have been reached.
The maximum deviation over 30 min from the temporal mean value assumed as half-width of a rectangular contribution with the expected value of 0.

$$|\delta T_{\mathrm{instab}}| \leq \max \left| \bar{T}_{\mathrm{ref}} - T_{\mathrm{ref,i}} \right| \qquad (5)$$

$$|\delta U_{\mathrm{instab}}| \leq \max \left| \bar{U}_{\mathrm{ref}} - U_{\mathrm{ref,i}} \right| \qquad (6)$$

The following results for the associated standard uncertainties:

$$u(\delta T_{\mathrm{instab}}) = \frac{1}{\sqrt{3}} \cdot \max \left| \bar{T}_{\mathrm{ref}} - T_{\mathrm{ref,i}} \right| \qquad (7)$$

$$u(\delta U_{\mathrm{instab}}) = \frac{1}{\sqrt{3}} \cdot \max \left| \bar{U}_{\mathrm{ref}} - U_{\mathrm{ref,i}} \right| \qquad (8)$$

The temporal instability is to be taken into account for calibration methods (A) to (D) and for all calibration temperatures and humidities and must be stated in the calibration certificate (see Appendix B and C).

8.3 Radiation influence $\delta T_{\mathrm{radiation}}$

There are three admissible procedures to estimate the contribution of the radiation influence to the measurement uncertainty, (see Chapter 7.4). For the individual procedures, the following uncertainty contributions result[9]:

- When using procedure (S1), 20 % of the difference determined should be taken into account as half-width of a rectangular contribution to the gas temperature.

$$|\delta T_{\mathrm{radiation}}| \leq 0{,}2 \cdot \max |T_{\mathrm{le}} - T_{\mathrm{he}}| \qquad (9)$$

$$u(\delta T_{\mathrm{radiation}}) = \frac{0{,}2}{\sqrt{3}} \cdot \max |T_{\mathrm{le}} - T_{\mathrm{he}}| \qquad (10)$$

- In procedure (S2), 100 % of the difference determined should be taken into account as half-width of a rectangular contribution as uncertainty contribution to the gas temperature.

$$|\delta T_{\mathrm{radiation}}| \leq \max |T_{\mathrm{le}} - T_{\mathrm{he}}| \qquad (11)$$

$$u(\delta T_{\mathrm{radiation}}) = \frac{1}{\sqrt{3}} \cdot \max |T_{\mathrm{le}} - T_{\mathrm{he}}| \qquad (12)$$

- In procedure (S3), 0.3 K is taken into account as half-width of a rectangular contribution as uncertainty contribution to the gas temperature.

$$|\delta T_{\mathrm{radiation}}| \leq 0.3\mathrm{K} \qquad (13)$$

$$u(\delta T_{\mathrm{radiation}}) = \frac{0.3\mathrm{K}}{\sqrt{3}} \qquad (14)$$

[9] If the requirements according to Chapter 7.4 regarding the emissivity of the thermometers are not met, the contributions applied to the measurement uncertainty must be increased beyond the components stated.

In calibration methods (A) to (D), the influence of radiation is to be taken into account for all calibration temperatures. The calibration certificate states the maximum differences of the respective procedure determined for the calculation of $\delta T_{\text{radiation}}$, i.e. **without** the above weighting factor [0.2 for procedure (S1)]. The evaluation of these values is made possible by specifying the underlying determination method.

8.4 Loading influence δT_{load} ; δU_{load}

As uncertainty contribution of the load, 20 % of the difference in the temperature of the reference measuring location (loaded state – empty useful volume) is taken as half-width of a rectangular contribution with the expected value of 0.

$$|\delta T_{\text{load}}| \leq 0.2 \cdot \max \left|T_{\text{ref}} - T_{\text{ref,load}}\right| \tag{15}$$

$$|\delta U_{\text{load}}| \leq 0.2 \cdot \max \left|U_{\text{ref}} - U_{\text{ref,load}}\right| \tag{16}$$

The following results for the associated standard uncertainties:

$$u(\delta T_{\text{load}}) = \frac{0.2}{\sqrt{3}} \cdot \max \left|T_{\text{ref}} - T_{\text{ref,load}}\right| \tag{17}$$

$$u(\delta U_{\text{load}}) = \frac{0.2}{\sqrt{3}} \cdot \max \left|U_{\text{ref}} - U_{\text{ref,load}}\right| \tag{18}$$

In the case of active loading with power dissipation, the difference determined is added to the uncertainty contribution of the loading (in the non-active state) as half-width of a rectangular contribution. For calibrations according to method (B), the load must be active during calibration. The difference in the temperature of the reference measuring location (loaded state - empty useful volume) (without weighting factor 0.2) is stated as loading influence in the calibration certificate (see Appendices B and C).

8.5 Influence of the ambient conditions δT_{env} ; δU_{env}

The ambient conditions during calibration are specified in the calibration certificate. The influence of ambient conditions that deviate from those during calibration (the admissible variation range according to the manufacturer's specifications must be observed) must be estimated if relevant for usage. Additional uncertainty contributions may have to be applied for such deviating conditions.

8.6 Resolution of the indication deviation $\delta T_{res,X}$; $\delta U_{res,X}$

The resolution of the indications for temperature and relative humidity are included as a rectangular uncertainty contribution. The smallest resolution is 0.5 digits. This is the half-width of a rectangular contribution with an expected value of 0.

8.7 Measurement error of the standard measuring device $\boldsymbol{\delta T_S}$; $\boldsymbol{\delta U_S}$

This contribution results from a partial budget for the standard measuring equipment used.

$$T_\mathrm{S} = T_\mathrm{ind,S} + \Delta T_\mathrm{S} + \delta T_\mathrm{S} \quad \text{with} \quad \delta T_\mathrm{S} = \delta T_\mathrm{cal} + \delta T_\mathrm{drift} + \delta T_\mathrm{res} + \delta T_\mathrm{sht} + \ldots \tag{19}$$

$$U_\mathrm{S} = U_\mathrm{ind,S} + \Delta U_\mathrm{S} + \delta U_\mathrm{S} \quad \text{with} \quad \delta U_\mathrm{S} = \delta U_\mathrm{cal} + \delta U_\mathrm{drift} + \delta U_\mathrm{res} + \ldots \tag{20}$$

When using resistance thermometers as standards, the self-heating δT_sht is to be taken into account.
In gas/air this can be considerably greater than in calibrations in liquid baths.
In the case of expanded measurement uncertainties (k = 2) smaller than 0.3 K in climatic chambers with air circulation, or smaller than 0.5 K in chambers without air circulation, this contribution must be taken into account by using different measuring currents during measurement or by appropriate determination in the calibration of the resistance thermometer in still or moving air. If measurement with different measuring currents is not possible, the contribution can also be determined by means of a comparative calibration in a liquid bath and in still or moving air (gas).

Depending on the selected method for determining the relative humidity (see Chapter 7.6), the calibration of the standards used as well as the consideration of the influencing factors must be carried out in accordance with relevant normative documents, if available; for example, in the case of relative humidity and hygrometers in accordance with DKD-R 5-8 [12].

9 Ambient conditions

Calibration should preferably be carried out at a stable ambient temperature. The admissible temperature range must be defined taking into account the specifications of the reference device used and must be documented.

If the absolute pressure is required for calculations, the ambient pressure must also be documented.

10 Calibration certificate

The calibration certificate must meet the requirements of the currently valid standards (DIN EN ISO/IEC 17025) [14] as well as the additional specifications of the respective accreditation body or regional metrology organisations.

In the calibration certificate the deviation of the indicated values from the measured reference values or, alternatively, the indication correction is stated as result.

Method (A), (B), (D)	The reference value for determining the deviation of the indication, the influence of radiation and, if applicable, the influence of loading refers to the reference measuring location (usually the spatial centre of the useful volume).
Method (C)	The reference value for determining the deviation of the indication as well as the influence of radiation and, if applicable, loading refers to the selected measuring location. If there are several measuring locations, it is sufficient to determine the influence of radiation in only one of the measuring locations.

The measuring conditions and the uncertainties of the indication deviations are stated. For the results of the additional investigations to characterise the conditions in the useful volume or the measuring location, the respective differences for the influence of radiation and loading as well as the inhomogeneity and instabilities are stated in accordance with sections 7.2 to 7.5, but not the resulting standard uncertainty contributions.

Here, the measurement methods must be clearly described in accordance with chapter 7.4 or assigned loads in accordance with chapter 7.5.

If certain investigations could not be carried out, this must be clearly indicated in the calibration certificate. The maximum values of the respective contributions to the measurement uncertainty must be estimated and taken into account.

All contributions not contained in the result and measurement uncertainty are to be referred to in the calibration certificate.

In the case of calibration method (C), the calibration item *must be* referred to in the calibration certificate as **“measuring location(s) in the climatic chamber”**.

Compliance with customer or manufacturer tolerances is checked at the customer’s request only.

In accordance with DIN EN ISO/IEC 17025:2018 [14], the underlying decision rule must be agreed with the customer and documented prior to calibration.

A complete calibration result consists of the following information (for examples, see Appendices B and C):

- deviation of the indication for the temperature and, if applicable, the relative humidity in the reference measuring location [methods (A), (B) and (D)] or for the individual measuring location(s) [method (C)],
- measurement uncertainty for the indication of the temperature and, if applicable, relative humidity,
- spatial distribution of temperature and, if applicable, relative humidity [methods (A), (B) and (D)],
- further test results for characterization, e.g. inhomogeneity, instability, influence of radiation, influence of loading,
- measuring conditions such as the position of the ventilation flap for incoming air, the setting of the circulation rate, e.g. rotational speed (if adjustable), etc.,
- carrier gas used,
- position of the measuring location,
- conformity statement for temperature / relative humidity (only on request by the customer).

The calibration certificate is accompanied by an information sheet (see Appendix D) stating the specific influence and error sources in practical application. This sheet is part of the calibration certificate (paper form / PDF format) and is numbered as the last page of the calibration certificate.

11 Bibliography

[1] DIN EN 60068-1:2015 Umgebungseinflüsse – Teil 1: Allgemeines und Leitfaden
English title: Environmental testing - Part 1: General and guidance

[2] DIN EN IEC 60068-3-5:2018 Umgebungseinflüsse – Teil 3-5: Unterstützende Dokumentation und Leitfaden, Bestätigung des Leistungsvermögens von Temperaturprüfkammern
English title: Environmental testing - Part 3-5: Supporting documentation and guidance - Confirmation of the performance of temperature chambers

[3] DIN EN IEC 60068-3-6:2018 Umgebungseinflüsse – Teil 3-6: Unterstützende Dokumentation und Leitfaden, Bestätigung des Leistungsvermögens von Temperatur- und Klima-Prüfkammern
English title: Environmental testing - Part 3-6: Supporting documentation and guidance - Confirmation of the performance of temperature/humidity chambers

[4] DIN EN IEC 60068-3-7:2022 Umgebungseinflüsse – Teil 3-7: Unterstützende Dokumentation und Leitfaden, Messungen in Temperaturprüfkammern für Prüfungen A (Kälte) und B (trockene Wärme) (mit Prüfgut)
English title: Environmental testing - Part 3-7: Supporting documentation and guidance - Measurements in temperature chambers for tests A (Cold) and B (Dry heat) (with load)

[5] DIN EN 60068-3-11:2008 Umgebungseinflüsse - Teil 3-11: Unterstützende Dokumentation und Leitfaden - Berechnung der Messunsicherheit von Umgebungsbedingungen in Klimaprüfkammern
English title: Environmental testing - Part 3-11: Supporting documentation and guidance - Calculation of uncertainty of conditions in climatic test chambers

[6] DIN 12880:2007 Elektrische Laborgeräte - Wärme- und Brutschränke
English title: Electrical laboratory devices - Heating ovens and incubators

[7] DIN 13277:2022 Kühl- und Gefrier-Lagerungsgeräte für Labor- und Medizinanwendungen - Terminologie, Anforderungen, Prüfung
English title: Refrigerators and freezers for laboratory and medical applications - Terminology, requirements, testing

[8] EA-4/02 M: 2022 Ermittlung der Messunsicherheit bei Kalibrierungen (German translation), approved EA 5 November 2021, Translation: 31.08.2022
English title: Evaluation of the Uncertainty of Measurement in Calibration

[9] JCGM 100:2008 Evaluation of measurement data - Guide to the expression of the uncertainty of measurement, Ausgabe September 2008

[10] DKD, Richtlinie DKD-R 5-1: Kalibrierung von Widerstandsthermometern, Physikalisch-Technische Bundesanstalt, Braunschweig and Berlin, Edition 11/2023, Revision 0.
English title: Calibration of resistance thermometers

[11] DKD, Richtlinie DKD-R 5-3: Kalibrierung von Thermoelementen, Physikalisch-Technische Bundesanstalt, Braunschweig and Berlin, Edition 09/2018, Revision 0.
English title: Calibration of thermocouples (only available in German language)

[12] DKD, Richtlinie DKD-R 5-8: Kalibrierung von Hygrometern zur direkten Erfassung der relativen Feuchte, Physikalisch-Technische Bundesanstalt, Braunschweig and Berlin, Edition 02/2019, Revision 0.
English title: Calibration of hygrometers for the direct measurement of relative humidity

[13] DKD, Richtlinie DKD-R 5-6: Bestimmung von Thermometerkennlinien, Physikalisch-Technische Bundesanstalt, Braunschweig and Berlin, Edition 09/2018, Revision 0.
English title: Determination of thermometer characteristics

[14] DIN EN ISO/IEC 17025:2018-03 Allgemeine Anforderungen an die Kompetenz von Prüf- und Kalibrierlaboratorien (ISO/IEC 17025:2017); German and English version EN ISO/IEC 17025:2017
English title: General requirements for the competence of testing and calibration laboratories

Appendix A Measurement uncertainty budgets (Example)

The cases discussed in this section for calculating the measurement uncertainty during calibration serve as examples and should not be directly transferred to an actual calibration. Rather, the contributions to the measurement uncertainty must be carefully determined individually in each case.

A1 – Temperature budget

Calibration of a climatic chamber with circulating air according to method (A) at a temperature of 120 °C with resistance thermometers as standard thermometers.

For the deviation ΔT_X of the temperature indication $T_{ind,X}$ of the climatic chamber from the gas temperature T_S measured with the standards for the reference measuring location, the following model is obtained:

$$\Delta T_X = T_{ind,X} - T_S + \delta T_S + \delta T_{inhom} + \delta T_{instab} + \delta T_{radiation} + \delta T_{load} + \delta T_{res,X} + \delta T_{env} \tag{21}$$

The following contributions result for the individual components of the model equation:

T_S:
Mean value of the temperature, measured with the standard thermometer, corrected by the associated indication correction.

The type A uncertainty contribution is determined from the standard deviation of the mean value for the multiple readings of the standard thermometer. In the example, the standard deviation of the mean value is 10 mK.

The type B contribution of the standard measuring device is determined from a partial budget for the temperature measurement.

$$T_S = T_{ind,S} + \Delta T_S + \delta T_S \tag{22}$$

$$\delta T_S = \delta T_{cal} + \delta T_{drift} + \delta T_{res} + \delta T_{sht} + \delta T_{int} + \delta T_{con} + \delta T_{thv} + \delta T_{htd} + \delta T_{hys} \tag{23}$$

δT_{cal}:
Correction of the temperature of the standard thermometer due to calibration.
The standard measuring device for the temperature is a Pt100 with the associated measuring instrument. The characteristic of the sensor is adjusted in the measuring instrument during calibration so that no corrections are to be applied to the temperature indication ($\Delta T_{cal} = 0$). The uncertainty U of the temperature is taken from the calibration certificate (U = 50 mK; k = 2). The associated standard uncertainty is 25 mK.

δT_{drift}:
Correction of the temperature of the standard thermometer due to drift since the last calibration. From the history of the thermometer, it is estimated that the uncertainty of the temperature due to the drift of the Pt100 (standard) since the last calibration does not exceed 50 mK (rectangular distribution). The associated standard uncertainty is 29 mK.

δT_{res}:
Correction of the temperature of the standard thermometer due to resolution. The resolution of the standard thermometer is 10 mK. The associated uncertainty is therefore a rectangular contribution with a width of 10 mK. The associated standard uncertainty is 2.9 mK.

δT_{sht}:
Correction of the temperature of the standard thermometer due to self-heating. From the investigation of the Pt100 (standard) in gas/air flow with different measuring currents it is estimated that the uncertainty of the temperature due the self-heating of the Pt100 does not exceed 30 mK (rectangular distribution). The associated standard uncertainty is then 17 mK.

δT_{int}:
Correction of the temperature of the standard thermometer due to interpolation between the calibration points. A rectangular contribution with a half-width of 20 mK is assumed. The associated standard uncertainty is then 12 mK (see also DKD-R 5-6, Table 6.2 [13]).

δT_{con}:
Correction of the temperature of the standard thermometer due to the connection technology of the standard thermometer. The Pt100 of the standard thermometer is connected to the associated measuring device using 4-wire technology. The contributions of the connection are therefore less than 1 mK. A rectangular contribution with a half-width of 1 mK is therefore used. The associated standard uncertainty is then 0.6 mK.

δT_{thv}:
Correction of the temperature of the standard thermometer due to parasitic thermoelectric voltages in the measuring circuit of the standard thermometer. The associated measuring device measures the resistance of the Pt100 standard thermometer with alternating direct current and averages over several polarity reversal periods. Any parasitic thermoelectric voltages in the measuring circuit are thus compensated for. The remaining residual uncertainty due to thermal voltages is therefore less than 1 mK. A rectangular contribution with a half-width of 1 mK is therefore assumed. The associated standard uncertainty is then 0.6 mK.

δT_{htd}:
Correction of the temperature of the standard thermometer due to heat dissipation. As the air temperature sensor of the standard is completely immersed and part of the cable runs inside the climatic chamber, this contribution can be neglected. A rectangular contribution with a half-width of 0 mK is therefore applied. The associated standard uncertainty is then 0 mK.

δT_{hys}:
Correction of the temperature of the standard thermometer due to hysteresis. Based on investigations with ascending and descending temperatures, a maximum uncertainty contribution of 10 mK is estimated. Therefore, a rectangular contribution with a half-width of 10 mK is assumed. The associated standard uncertainty is then 6 mK.

The following contributions result for the calibration item:

$T_{\mathrm{ind,\,X}}$:
The temperature indication of the climatic chamber is obtained from the mean value of the readings over a period of 30 min. The associated uncertainty is formed by the standard deviation of the mean value of 130 mK (normal distribution)

The associated standard uncertainty is then 130 mK.

$\delta T_{\mathrm{inhom}}$:
The temperature inhomogeneity is determined from the measurement results for the individual measuring locations i in relation to the reference measuring location (see Chapter 8.1). The largest difference between all temperatures and the temperature in the reference measuring location is 0.5 K (half-width of the rectangular uncertainty contribution). The associated standard uncertainty is then 289 mK.

$\delta T_{\mathrm{instab}}$:
The temperature instability is determined from a series of measurements for the reference measuring location. The maximum temperature instability thus determined is used for the measurement uncertainty calculation. The maximum deviation within 30 min from the mean value over this period is 0.3 K (half-width of the rectangular uncertainty contribution; see Chapter 8.2). The associated standard uncertainty is then 173 mK.

$\delta T_{\mathrm{radiation}}$:
The influence of radiation on the temperature measurement is determined using procedure (S1) (see Sections 7.4 and 8.3) using two thermometers with low and high emissivity respectively. The difference determined between the temperatures of the two thermometers is 2 K. 20 % of this value is taken as half-width of a rectangular uncertainty contribution. The associated standard uncertainty is then 231 mK.

δT_{load}:
For the reference measuring location, the temperature is measured in the unloaded climatic chamber and in the climatic chamber loaded according to customer specifications. The difference is 0.8 K. 20 % of this value is taken as half-width of a rectangular uncertainty contribution (see Section 8.4). The associated standard uncertainty is then 92 mK.

$\delta T_{\mathrm{res,X}}$:
The resolution of the temperature indication of the climatic chamber is 0.1 K. The associated uncertainty is therefore a rectangular contribution with a width of 100 mK. The associated standard uncertainty is then 29 mK.

δT_{env}:
Deviation of the temperature due to deviating ambient conditions during use, see Chapter 8.5. Only relevant if the ambient conditions during calibration and use are different; will be omitted in the following.

Thus, the following measurement uncertainty budget is obtained (Table 6).

Table 6: Measurement uncertainty budget for the calibration of a climatic chamber with circulating air according to method (A) at a temperature of 120 °C

Quantity	Description	Estimate	Uncertainty or half-width	Standard uncertainty	Distribution	Divisor	Sensitivity coefficient	Uncertainty contribution
T_S	Indication standard thermometer	121.22 °C	0.024 K	0.024 K	normal	1	1	0.024 K
δT_{cal}	Calibration standard thermometer	0	0.050 K	0.025 K	normal	2	1	0.025 K
δT_{drift}	Drift standard thermometer	0	0.050 K	0.029 K	rectangular	√3	1	0.029 K
δT_{res}	Resolution standard thermometer	0	0.005 K	0.003 K	rectangular	√3	1	0.003 K
δT_{sht}	Self-heating Pt100	0	0.030 K	0.017 K	rectangular	√3	1	0.017 K
δT_{int}	Interpolation between calibration points	0	0.020 K	0.012 K	rectangular	√3	1	0.012 K
δT_{con}	Connection standard thermometer	0	0.001 K	0.001 K	rectangular	√3	1	0.001 K
δT_{thv}	Parasitic thermoelectric voltage standard thermometer	0	0.001 K	0.001 K	rectangular	√3	1	0.001 K
δT_{htd}	Heat dissipation standard thermometer	0	0.000 K	0.000 K	rectangular	√3	1	0.000 K
δT_{hys}	Hysteresis standard thermometer	0	0.010 K	0.006 K	rectangular	√3	1	0.006 K
$T_{ind,X}$	Indication Climatic chamber temperature	120.0 °C	0.130 K	0.130 K	normal	1	1	0.130 K
δT_{inhom}	Temperature inhomogeneity	0	0.500 K	0.289 K	rectangular	√3	1	0.289 K
δT_{instab}	Temperature instability	0	0.300 K	0.173 K	rectangular	√3	1	0.173 K
$\delta T_{radiation}$	Radiation influence	0	0.400 K	0.231 K	rectangular	√3	1	0.231 K
δT_{load}	Loading influence	0	0.160 K	0.092 K	rectangular	√3	1	0.092 K
$\delta T_{res,X}$	Resolution	0	0.050 K	0.029 K	rectangular	√3	1	0.029 K
ΔT_X	Deviation of the indication	-1.2 K					u = 0.442 K	

The expanded measurement uncertainty for the calibration of the temperature indication of the climatic chamber in relation to the useful volume is

$$U = k \cdot u(\Delta T_\mathrm{X}) = 2 \cdot 442\ \mathrm{mK} \cong 0.89\ \mathrm{K}.$$

If a rectangular contribution, e.g. the inhomogeneity or similar, clearly outweighs all other contributions in this budget, a coverage factor $k \neq 2$ is to be applied for a coverage probability of approximately 95 % because the measurement uncertainty is then not based on a normal distribution. Since in this example several rectangular contributions of almost equal magnitude contribute to the combined total measurement uncertainty, a normal distribution can be approximately assumed here, and the coverage factor can be assumed as $k = 2$. With the effective degrees of freedom for the standard measurement uncertainty of the result being too small, a coverage factor $k > 2$ may also result.

A2 – Budget for relative humidity (example for determining the reference humidity by using a dew point hygrometer as standard):

Calibration of a climatic chamber according to method (A) at a relative humidity of 50 % at an air temperature of 25 °C using a dew point hygrometer with an external measuring head according to procedure (F1) and resistance thermometers as standards.

For the deviation ΔU_X of the indication of the relative humidity $U_\mathrm{ind,X}$ of the climatic chamber from the relative humidity $U_\mathrm{w,S}$ determined for the reference measuring location by means of the standard the following model is obtained:

$$\Delta U_\mathrm{X} = U_\mathrm{ind,X} - U_\mathrm{w,S} + \delta U_\mathrm{w,S} + \delta U_\mathrm{inhom} + \delta U_\mathrm{instab} + \delta U_\mathrm{load} + \delta U_\mathrm{res,X} + \delta U_\mathrm{env} \qquad (24)$$

The reference humidity $U_\mathrm{w,S}$ is calculated from the gas and dew point temperature measured in the reference measuring location and the absolute pressure.

The deviation of the relative humidity indicated by the calibration item from the reference humidity measured in the climatic chamber represents the calibration result.

The measurement uncertainty calculation for the calibration result is carried out in several sub-steps.

Step 1 *Measurement uncertainty budget for the gas temperature*

Step 2 *Measurement uncertainty budget for the dew point temperature*

Step 3 *Measurement uncertainty budget for the calculation of the relative humidity*

Step 4 *Measurement uncertainty budget for the calibration result*

In the following, the model equations and their components in the above-mentioned sub-steps will be explained in detail and summarised in measurement uncertainty budgets.

Step 1: Gas temperature

The uncertainty budget for the gas temperature consists of the contributions for the standard thermometer.

The contributions of the climatic chamber are not yet included in this sub-step. These are taken into account in sub-step 4.

For the gas temperature T_S, the following model equation applies:

$$T_\mathrm{S} \; = \; T_\mathrm{ind,S} + \Delta T_\mathrm{S} + \delta T_\mathrm{S} \tag{25}$$

$$\delta T_\mathrm{S} \; = \delta T_\mathrm{cal} + \delta T_\mathrm{drift} + \delta T_\mathrm{res} + \delta T_\mathrm{sht} + \delta T_\mathrm{int} + \delta T_\mathrm{con} + \delta T_\mathrm{thv} + \delta T_\mathrm{htd} + \delta T_\mathrm{hys} \tag{26}$$

For the individual components of the model equation the following contributions result:

T_S:
Mean value of the temperature, measured with the standard thermometer, corrected by the associated indication correction
The type A uncertainty contribution is determined from the standard deviation of the mean value for the multiple readings of the standard thermometer. In the example, the standard deviation of the mean value is 10 mK.

δT_cal:
Correction of the temperature of the standard thermometer due to calibration. The standard measuring device for the temperature is a Pt100 with associated measuring instrument. The characteristic curve of the sensor is adjusted in the measuring instrument during calibration so that no corrections need to be made to the temperature indication ($\Delta T_\mathrm{cal} = 0$). The uncertainty U of the temperature is taken from the calibration certificate (U = 50 mK; normal distribution, k = 2). The associated standard uncertainty is 25 mK.

δT_drift:
Correction of the temperature of the standard thermometer due to drift since the last calibration. From the history of the thermometer, it is estimated that the uncertainty of the temperature due to the drift of the Pt100 (standard) since the last calibration does not exceed 50 mK (rectangular distribution). The associated standard uncertainty is 29 mK.

δT_res :
Correction of the temperature of the standard thermometer due to resolution. The resolution of the standard thermometer is 10 mK. The associated uncertainty is therefore a rectangular contribution with a width of 10 mK. The associated standard uncertainty is 2.9 mK.

δT_sht:
Correction of the temperature of the standard thermometer due to self-heating. From the investigation of the Pt100 (standard) in gas/air flow with different measuring currents it is estimated that the uncertainty of the temperature due to the self-heating of the Pt100 does not exceed 30 mK (rectangular distribution). The associated standard uncertainty is then 17 mK.

δT_{int}:
Correction of the temperature of the standard thermometer due to interpolation between the calibration points. A rectangular contribution with a half-width of 20 mK is assumed. The associated standard uncertainty is 12 mK (see also DKD-R 5-6, Table 6.2 [13]).

δT_{con}:
Correction of the temperature of the standard thermometer due to the connection technology. The Pt100 of the standard thermometer is connected to the associated measuring device using 4-wire technology. The contributions of the connection are therefore less than 1 mK. Therefore, a rectangular contribution with a half-width of 1 mK is applied. The associated standard uncertainty is 0.6 mK.

δT_{thv}:
Correction of the temperature of the standard thermometer due to parasitic thermoelectric voltages in the measuring circuit of the standard thermometer. The associated measuring device measures the resistance of the Pt100 standard thermometer with alternating direct current and averages over several polarity reversal periods. Any parasitic thermoelectric voltages in the measuring circuit are thus compensated for. The remaining residual uncertainty due to thermoelectric voltages is therefore less than 1 mK. A rectangular contribution with a half-width of 1 mK is therefore applied. The associated standard uncertainty is 0.6 mK.

δT_{htd}:
Correction of the temperature of the standard thermometer due to heat dissipation of the standard thermometer. As the air temperature sensor of the standard is completely immersed and part of the cable still runs in the climatic chamber, this contribution can be neglected. A rectangular contribution with a half-width of 0 mK is therefore applied. The associated standard uncertainty is then 0 mK.

δT_{hys}:
Correction of the temperature of the standard thermometer due to hysteresis. Based on investigations with ascending and descending temperatures, a maximum uncertainty contribution of 10 mK is estimated. A rectangular contribution with a half-width of 10 mK is therefore applied. The associated standard uncertainty is 6 mK.

The contributions are summarised in Table 7.

Table 7: Measurement uncertainty budget for the gas temperature

Quantity	Description	Estimate	Uncertainty or half-width	Standard uncertainty	Distribution	Divisor	Sensitivity coefficient	Uncertainty contribution
$T_{\mathrm{ind,S}}$	Indication standard thermometer	24.70 °C	0.010 K	0.010 K	normal	1	1	0.010 K
δT_{cal}	Calibration standard thermometer	0	0.050 K	0.025 K	normal	2	1	0.025 K
$\delta T_{\mathrm{drift}}$	Drift standard thermometer	0	0.050 K	0.029 K	rectangular	√3	1	0.029 K
$\delta T_{\mathrm{res,\ std}}$	Resolution standard thermometer	0	0.005 K	0.003 K	rectangular	√3	1	0.003 K
δT_{heat}	Self-heating Pt100	0	0.030 K	0.017 K	rectangular	√3	1	0.017 K
δT_{int}	Interpolation between. Calibration points	0	0.020 K	0.012 K	rectangular	√3	1	0.012 K
δT_{con}	Connection standard thermometer	0	0.001 K	0.001 K	rectangular	√3	1	0.001 K
δT_{thv}	Parasitic thermoelectric voltage standard thermometer	0	0.001 K	0.001 K	rectangular	√3	1	0.001 K
δT_{htd}	Heat dissipation standard thermometer	0	0.000 K	0.000 K	rectangular	√3	1	0.000 K
δT_{hys}	Hysteresis standard thermometer	0	0.010 K	0.006 K	rectangular	√3	1	0.006 K
T_{S}	Gas temperature	24.70 °C					u = 0.046 K	

Step 2: Dew point temperature

The uncertainty budget of the dew point temperature consists of the contributions for the dew point hygrometer.

The contributions of the climatic chamber are not yet included in this sub-step. These are taken into account in sub-step 4.

For the dew point temperature $T_{\mathrm{d,S}}$, the following model equation applies:

$$T_{\mathrm{d,S}} = T_{\mathrm{d,ind,S}} + \Delta T_{\mathrm{d,S}} + \delta T_{\mathrm{d,cal}} + \delta T_{\mathrm{d,res}} + \delta T_{\mathrm{d,int}} + \delta T_{\mathrm{d,drift}} + \delta T_{\mathrm{d,rep}} - c_{\mathrm{Td}} \cdot \delta T_{\mathrm{d,Tdep}} \tag{27}$$

For the individual components of the model equation the following contributions result:

$T_{\mathrm{d,S}}$:
Mean value of the dew point temperature, measured with the standard dew point hygrometer, corrected by the corresponding indication correction
The type A uncertainty contribution is determined from the standard deviation of the mean value for the multiple readings of the standard dew point hygrometer. In the example, the standard deviation of the mean value is 10 mK.

$\delta T_{\mathrm{d,cal}}$:
Correction of the dew point temperature of the standard dew point hygrometer due to calibration. During calibration, a deviation of + 0.02 K was detected in the standard dew point hygrometer. This is corrected during evaluation. The uncertainty U of the dew point deviation is taken from the calibration certificate (U = 50 mK; normal distribution, $k = 2$). The associated standard uncertainty is therefore 25 mK.

$\delta T_{\mathrm{d,res}}$:
Correction of the dew point temperature of the standard dew point hygrometer due to resolution. The resolution of the dew point indication is 10 mK. A rectangular contribution with a half-width of 5 mK is therefore applied. The associated standard uncertainty is then 2.9 mK.

$\delta T_{\mathrm{d,int}}$:
Correction of the dew point temperature of the standard dew point hygrometer due to interpolation between the calibration points. A rectangular contribution with a half-width of 20 mK is applied. The associated standard uncertainty is then 12 mK.

$\delta T_{\mathrm{d,drift}}$:
Correction of the dew point temperature of the standard dew point hygrometer due to drift since the last recalibration. The last calibrations of the standard resulted in a maximum drift of 50 mK per year. A rectangular contribution with a half-width of 50 mK is therefore applied. The associated standard uncertainty is then 29 mK.

$\delta T_{\mathrm{d,rep}}$:
Correction of the dew point temperature of the standard dew point hygrometer due to repeatability. It is known from investigations with a stable dew point and repeated adjustment of the standard dew point hygrometer that the repeatability can be up to 50 mK. A rectangular contribution with a half-width of 50 mK is therefore applied. The associated standard uncertainty is then 29 mK.

$\delta T_{\mathrm{d,Tdep}}$:
Correction of the dew point temperature due to the dependence of the measurement of the standard dew point hygrometer on the ambient temperature. It is known from investigations with a fixed dew point at different ambient temperatures that the standard dew point hygrometer has an ambient temperature dependence c_{Td} of the dew point of 5 mK / K (c_{Td} = 5 mK / K). The standard dew point hygrometer is calibrated in steps of 10 K at different ambient temperatures. Each of these calibrations therefore covers an ambient temperature range of ± 5 K. A rectangular contribution with a half-width of 5 K is therefore applied. The associated standard uncertainty is then 2.9 K and the standard uncertainty contribution to the dew point 14 mK.

The contributions are summarised in Table 8.

Table 8: Measurement uncertainty budget for the dew point temperature

Quantity	Description	Estimate	Uncertainty or half-width	Standard uncertainty	Distribution	Divisor	Sensitivity coefficient	Uncertainty contribution
$T_{\mathrm{d,ind,S}}$	Indication dew point hygrometer	14.10 °C	0.010 K	0.010 K	normal	1	1	0.010 K
$\delta T_{\mathrm{d,cal}}$	Deviation dew point hygrometer from calibration	-0.02 K	0.050 K	0.025 K	normal	2	1	0.025 K
$\delta T_{\mathrm{d,res}}$	Resolution dew point hygrometer	0	0.005 K	0.003 K	rectangular	√3	1	0.003 K
$\delta T_{\mathrm{d,int}}$	Interpolation between calibration points	0	0.020 K	0.012 K	rectangular	√3	1	0.012 K
$\delta T_{\mathrm{d,drift}}$	Drift dew point hygrometer	0	0.050 K	0.029 K	rectangular	√3	1	0.029 K
$\delta T_{\mathrm{d,rep}}$	Repeatability dew point measurement	0	0.050 K	0.029 K	rectangular	√3	1	0.029 K
$\delta T_{\mathrm{d,Tdep}}$	Temperature dependence measuring head dew point hygrometer	0	5.000 K	2.887 K	rectangular	√3	0.005 K/K	0.014 K
$T_{\mathrm{d,S}}$	Dew point temperature	14.08 °C					u = 0.053 K	

Step 3: Calculation of the relative humidity (reference humidity)

The reference humidity [12] is calculated from the gas and dew point temperature and the absolute pressure using the following equation:

$$U_{\mathrm{w,S}} = \frac{e(T_{d,S})\cdot f_w(T_{d,S},p)}{e_w(T_S)\cdot f_w(T_S,p)} \cdot 100\ \% \qquad (28)$$

For the unknown deviation $\delta U_{\mathrm{w,S}}$ of the calculated reference humidity the following model equation applies:

$$\delta U_{\mathrm{w,S}} \ = \ c_T \cdot \delta T_{\mathrm{S}} + c_{Td} \cdot \delta T_{\mathrm{d,S}} + c_p \cdot \delta p + \delta U_{\mathrm{S,A}} \qquad (29)$$

For the individual components of the model equation the following contributions result:

δT_{S}:
Gas temperature measured with the standard thermometer.
The uncertainty of the gas temperature is the result of the corresponding sub-budget according to Table 7. The contribution has a normal distribution.
The corresponding sensitivity coefficient at 24.7 °C and a relative humidity of 51.6 % is c_{T} = 3.09 % / K.

$\delta T_{\mathrm{d,S}}$:
Dew point measured with the standard dew point hygrometer.
The uncertainty of the dew point is the result of the corresponding sub-budget according to Table 8. The contribution has a normal distribution.
The corresponding sensitivity coefficient at 24.7 °C and a relative humidity of 51.6 % is c_{T} = 3.35 % / K.

δp:
The absolute pressure only enters into the enhancement factors. The corresponding sensitivity coefficients are very small, so that these contributions can be neglected.

$\delta U_{\mathrm{S,A}}$:
Calculation of relative humidity from gas and dew point temperature.
The uncertainty from the vapour pressure equation used for the saturation vapour pressure (calculated from the gas temperature) and for the water vapour partial pressure (calculated from the dew point temperature) is estimated at 0.02 %. A rectangular contribution with a half-width of 0.02 % is applied. The associated standard uncertainty is then 0.012 %.

These contributions are summarised in Table 9.

Table 9: Measurement uncertainty budget for the calculated reference humidity

Quantity	Description	Estimate	Uncertainty or half-width	Standard uncertainty	Distribution	Divisor	Sensitivity coefficient	Uncertainty contribution
T_S	Gas temperature	24.70 °C	0.046 K	0.046 K	normal	1	3.09 %/K	0.142 %
$\delta T_{d,S}$	Dew point temperature	14.08 °C	0.053 K	0.053 K	normal	1	3.35 %/K	0.177 %
$\delta U_{S,A}$	Formula error	0.00	0.02 %	0.012 %	rectangular	√3	1	0.012 %
$U_{w,S}$	Calculated reference humidity	51.6 %					u = 0.227 %	

Step 4: Calibration result

The deviation of the relative humidity indicated by the calibration item from the reference humidity measured in the climatic chamber represents the calibration result. The uncertainty of the reference humidity and the uncertainty contributions of the calibration item are assigned to the calibration result.

By assuming a normal distribution and multiplying the standard measurement uncertainty by the coverage factor $k = 2$, the expanded measurement uncertainty U is obtained.

The following model equation applies to the calibration result (deviation of the calibration item):

$$\Delta U_{\mathrm{X}} = U_{\mathrm{ind,X}} - U_{\mathrm{w,S}} + \delta U_{\mathrm{w,S}} + \delta U_{\mathrm{inhom}} + \delta U_{\mathrm{instab}} + \delta U_{\mathrm{load}} + \delta U_{\mathrm{res,X}} + \delta U_{\mathrm{env}} \tag{30}$$

For the individual components of the model equation the following contributions result:

$U_{\mathrm{w,S}}$:
Humidity reference value, calculated from the gas temperature measured with the standard thermometer and the dew point temperature in the climatic chamber measured with the standard dew point hygrometer.

$\delta U_{\mathrm{w,S}}$:
The uncertainty of the reference humidity is obtained as result of the corresponding sub-budget according to Table 9. The contribution is assumed to have a normal distribution.

$U_{\mathrm{ind,X}}$:
The indication for the relative humidity in the climatic chamber results from the mean value of the readings over a period of 30 min. The associated uncertainty is formed by the standard deviation of the mean value of 0.24 % in the example (normal distribution). The associated standard uncertainty is then 0.24 %.

$\delta U_{\mathrm{inhom}}$:
The humidity inhomogeneity is determined from the measurement results for the individual measurement locations i in relation to the reference measurement location (see Chapter 8.1). The largest difference between all relative humidities and the relative humidity in the reference measurement location (usually the centre of the useful volume) is 1.8 % (half-width of the rectangular uncertainty contribution). The associated standard uncertainty is then 1.04 %.

$\delta U_{\mathrm{instab}}$:
The instability of the humidity is determined from a series of measurements for the reference measuring location.
The thus determined maximum instability of the relative humidity is used for calculating the measurement uncertainty. The largest deviation from the mean value within 30 min is 1.2 % (half-width of the rectangular uncertainty contribution; see Chapter 8.2). The associated standard uncertainty is then 0.69 %.

δU_{load}:
For the reference measuring location, the relative humidity is measured in the unloaded climatic chamber and in the climatic chamber loaded according to customer specifications (method B). The difference is 2.2 %. 20 % of this value is taken as half-width of a rectangular uncertainty contribution (see Chapter 8.4). The associated standard uncertainty is then 0.25 %.

$\delta U_{\mathrm{res,X}}$:
The resolution of the relative humidity shown by the indication of the climatic chamber is 1.0 %. The associated uncertainty is therefore a rectangular contribution with a width of 1.0 %. The associated standard uncertainty is then 0.29 %.

δU_{env}:
Deviation of the relative humidity due to deviating ambient conditions during use. Only relevant if the ambient conditions during calibration and use are different; will be omitted in the following.

These contributions are summarised in Table 10.

Table 10: Measurement uncertainty budget *calibration result*

Quantity	Description	Estimate	Uncertainty or half-width	Standard uncertainty	Distribution	Divisor	Sensitivity coefficient	Uncertainty contribution
$U_{w,S}$	Calculated reference humidity	51.6 %	0.23 %	0.23 %	normal	1	1.0	0.23 %
$U_{ind,X}$	Humidity indication calibration item	50 %	0.24 %	0.24 %	normal	1	1.0	0.24 %
δU_{inhom}	Humidity inhomogeneity	0.0 %	1.8 %	1.04 %	rectangular	√3	1.0	1.04 %
δU_{instab}	Humidity instability	0.0 %	1.2 %	0.69 %	rectangular	√3	1.0	0.69 %
δU_{load}	Loading influence	0.0 %	0.44 %	0.25 %	rectangular	√3	1.0	0.25 %
$\delta U_{res,X}$	Resolution	0.0 %	0.5 %	0.29 %	rectangular	√3	1.0	0.29 %
ΔU_X	Deviation of the indication calibration item	-1.6 %					u = 1.35 %	

At 25 °C and 51.6 %, the climatic chamber has an indication deviation of -1.6 %, with an expanded measurement uncertainty U (based on the assumption of a normal distribution and the coverage factor $k = 2$) of 2.7 %.

If in this budget a rectangular contribution, e.g. the inhomogeneity or similar, clearly outweighs all other contributions, a coverage factor of $k \neq 2$ is to be applied for a coverage probability of approximately 95 %, because the measurement uncertainty is then not based on a normal distribution. Since in this example several rectangular contributions of almost the same order of magnitude contribute to the combined total measurement uncertainty, a normal distribution can be approximately assumed here, and the coverage factor can be assumed to be $k = 2$. With the effective degrees of freedom for the standard measurement uncertainty of the result being too small, a coverage factor $k > 2$ may also result.

A3 – Budget for relative humidity (example for determining the reference humidity by using capacitive humidity sensors as a standard)

Calibration of a ***measuring location*** in a climatic chamber according to ***method (C)*** at a relative humidity of 50 % at 23 °C with two standard hygrometers (capacitive polymer sensors) according to procedure (F3) and using resistance thermometers as standards

The following model results for the deviation ΔU_X of the indication of the relative humidity $U_\mathrm{ind,X}$ of the climatic chamber from the relative humidity $U_\mathrm{w,S}$ measured with the standards for the measuring location:

$$\Delta U_\mathrm{X} = U_\mathrm{ind,X} - U_\mathrm{w,S} + \delta U_\mathrm{w,S} + \delta U_\mathrm{inhom} + \delta U_\mathrm{instab} + \delta U_\mathrm{load} + \delta U_\mathrm{res,X} + \delta U_\mathrm{env} \quad (31)$$

To determine the humidity reference value $U_\mathrm{w,S}$ the following model equation applies:

$$\begin{aligned} U_\mathrm{w,S} = {} & U_S \\ & + \tfrac{1}{2} \cdot \delta U_\mathrm{cal,S1} + \tfrac{1}{2} \cdot \delta U_\mathrm{res,S1} + \tfrac{1}{2} \cdot \delta U_\mathrm{int,S1} + \tfrac{1}{2} \cdot \delta U_\mathrm{drift,S1} + \tfrac{1}{2} \cdot \delta U_\mathrm{hys,S1} \\ & + \tfrac{1}{2} \cdot \delta U_\mathrm{cal,S2} + \tfrac{1}{2} \cdot \delta U_\mathrm{res,S2} + \tfrac{1}{2} \cdot \delta U_\mathrm{int,S2} + \tfrac{1}{2} \cdot \delta U_\mathrm{drift,S2} + \tfrac{1}{2} \cdot \delta U_\mathrm{hys,S2} \\ & + \delta U_\mathrm{i,S1-2} + \delta U_\mathrm{Tdep} + c_\mathrm{T} \cdot (\delta T_\mathrm{htd} + \delta T_\mathrm{sht}) \end{aligned} \quad (32)$$

The sensitivity coefficient c_T at a temperature of 23 °C and a relative humidity of 52.2 % is c_T = 3.16 % / K.

This model equation applies in the event that the contributions (calibration, resolution, interpolation, drift and hysteresis) of the two standard hygrometers can be assumed to be uncorrelated. This is approximately the case, for example, if both standard hygrometers have not been calibrated at the same time by the same calibration laboratory using the same standards. Ideally, the calibration dates of both standards are shifted by half the calibration period. The drift and hysteresis have little or no correlation, especially if different measurement methods are used for the working standards (e.g. capacitive and resistive-electrolytic) or if humidity sensors from different manufacturers are used. Another option would be to avoid using the two standards together in calibrations so that they are not constantly exposed to identical influences.
If the contributions of both standards are considered to be correlated because the above conditions are not met, the respective contributions should be summarised as associated uncertainty contribution of the mean value, taking into account the correlation. This summarised value should then be used in the measurement uncertainty budget instead of the two individual contributions (for estimating a maximum value for this summarised uncertainty contribution, see also EA-4/02 M: 2022, Appendix D [8]).

The following contributions result for the individual components of the model equation of the humidity reference value:

U_S :
The mean value of the relative humidity indications of the two standards corrected with the associated indication corrections is determined from all individual measurements of the standard hygrometers. The type A uncertainty contribution is determined from the standard deviation of the mean value for the multiple readings of the standard hygrometers.

The example shows a mean value of 52.2 % and a standard deviation of 0.04 % for the mean value.

$\delta U_{\mathrm{cal,S1}}, \delta U_{\mathrm{cal,S2}}$:
Correction of the relative humidity of the standard hygrometers due to calibration. The standard hygrometers are resistive-electrolytic or capacitive humidity sensors with corresponding measuring devices. Before calculating the mean value of both hygrometers, the indication of each standard hygrometer is corrected using the indication correction of the corresponding calibration certificate. The uncertainty U of the relative humidity deviation is taken from the calibration certificate (U = 0.6 %; normal distribution, $k = 2$). The associated standard uncertainty is therefore 0.3 %.

$\delta U_{\mathrm{drift,S1}}, \delta U_{\mathrm{drift,S2}}$:
Correction of the averaged relative humidity of the standard hygrometers due to the drift since the last recalibration of the history of the hygrometers. It is estimated that the uncertainty of the humidity measurement due to the drift since the last calibration does not exceed a relative humidity of 1.0 % (rectangular distribution). The associated standard uncertainty is then 0.58 %.

$\delta U_{\mathrm{res,S1}}, \delta U_{\mathrm{res,S2}}$:
Correction of the averaged relative humidity of the standard hygrometers due to resolution.
The resolution of the relative humidity indicated by the standard hygrometer is 0.1 %. The associated uncertainty is therefore a rectangular contribution with a width of 0.1 %. The associated standard uncertainty is then 0.03 %.

$\delta U_{\mathrm{int,S1}}, \delta U_{\mathrm{int,S2}}$:
Correction of the relative humidity indication of the standard hygrometers due to interpolation between the calibration points. A rectangular contribution with a half-width of 0.25 % is assumed. The associated standard uncertainty is then 0.14 %.

$\delta U_{\mathrm{hys,S1}}, \delta U_{\mathrm{hys,S2}}$:
Correction of the relative humidity indication of the standard hygrometers due to a possible hysteresis. An investigation revealed only minor hysteresis effects for both standard hygrometers. Each calibration point is only approached with increasing relative humidity. In this case, the hysteresis is corrected accordingly based on the investigations (but may have to be taken into account in other processes). A rectangular contribution with a half-width of 0.0 % is assumed. The associated standard uncertainty is then 0.0 %.

$\delta U_{\mathrm{i,S1-2}}$:
Correction of the averaged relative humidity of the standard hygrometers due to the difference between the corrected readings of the two standard hygrometers. The difference in the measured relative humidity observed between the two standard hygrometers must not be greater than ±0.42 % (= 0.7 · $U_{\mathrm{cal,S}}$). If the measurement uncertainties differ, the larger uncertainty must be used as the worst case.
If the difference is not within these limits, the observations should be repeated and/or the reasons for the large differences found should be investigated in more detail. Both hygrometers have an indication difference of 0.3 %. The criterion is therefore fulfilled, and the mean value of the indications is used as reference value. As long as the difference between the indications of the two standard hygrometers is significantly smaller than the uncertainty of the calibration of the

standard hygrometers, no additional measurement uncertainty contribution needs to be applied to the mean value. A rectangular contribution with a half-width of 0.0 % is therefore assumed. The associated standard uncertainty is then 0.0 %.

If the difference between the corrected indications of the two standards is greater than 0.7 times the expanded calibration uncertainty of the standards and the causes are not investigated and the measurements are not repeated, then the difference between the indications of the two standards should be taken as half- width of the rectangular distribution.

δU_{Tdep}:
Correction of the averaged relative humidity of the standard hygrometers due to the dependence of the humidity measurement of the standard hygrometers on the gas temperature. The relative humidity of the standard hygrometers was calibrated at several points at 20 °C and 25 °C. An interpolation is carried out in between. Due to the interpolation, a rectangular contribution with a half-width of 0.35 % is assumed. The associated standard uncertainty is then 0.20 %.
If the standard hygrometers are of different types, a non-correlated behaviour can also be assumed here (see contributions to calibration, drift, …).

δT_{htd}:
Correction of the averaged relative humidity of the standard hygrometers due to heat dissipation. As the sensors of the standards are completely immersed and part of the cable runs in the climatic chamber, this contribution can be neglected. A rectangular contribution with a half-width of 0 mK is therefore assumed. The associated standard uncertainty is then 0 mK.

δT_{sht}:
Correction of the averaged relative humidity of the standard hygrometers due to self-heating. A maximum uncertainty contribution of 0.1 K is estimated based on investigations regarding the flow velocities of the standard hygrometers used. A rectangular contribution with a half-width of 0.1 K is therefore assumed. The associated standard uncertainty is then 0.06 K. The associated sensitivity coefficient has a value of c_T= 3.16 % / K at 23 °C and 52.2 %.

The following contributions result for the calibration item:

$U_{\mathrm{ind,X}}$:
The indication for the relative humidity in the climatic chamber results from the mean value of the readings over a period of 30 min. The associated uncertainty is formed by the standard deviation of the mean value of 0.24 % in the example (normal distribution). The associated standard uncertainty is then 0.24.

$\delta U_{\mathrm{inhom}}$:
The local humidity inhomogeneity is determined from the measurement results for the individual measurement location i by using a further humidity sensor at a distance of 2 cm to 5 cm from the neighbouring sensor.
The thus determined maximum local humidity inhomogeneity of the relative humidity in the measurement location i is 0.6 % (half-width of the rectangular uncertainty contribution). The associated standard uncertainty is then 0.35.

$\delta U_{\mathrm{instab}}$:
The humidity instability is determined from a measurement series for the measurement location. The thus determined maximum instability of the relative humidity in the measurement location i is used for the measurement uncertainty calculation. The largest deviation within 30 min from the mean value in the measuring location i is 0.5 % (half-width of the rectangular uncertainty contribution; see Chapter 8.2). The associated standard uncertainty is then 0.29

δU_{load}:
For the reference measuring location, the relative humidity is measured in the unloaded climatic chamber and in the climatic chamber loaded according to customer specifications (method B). The difference is 2.2 %. 20 % of this value is taken as half-width of a rectangular uncertainty contribution (see Chapter 8.4). The associated standard uncertainty is then 0.26 %.

$\delta U_{\mathrm{res,X}}$:
The resolution of the relative humidity displayed by the indication of the climatic chamber is 1.0 %. The associated uncertainty is therefore a rectangular contribution with a width of 1.0 %. The associated standard uncertainty is then 0.29 %.

δU_{env}:
Deviation of the relative humidity due to deviating ambient conditions during use. Only relevant if the ambient conditions during calibration and use are different; will be neglected in the following.

This results in the following uncertainty budget (Table 11) for the calibration of a **measuring location** in a climatic chamber according to **method (C)** at a relative humidity of 50 % at 23 °C.

Table 11: Measurement uncertainty budget for the calibration of a **measuring location** in the climatic chamber according to **method C** at a relative humidity of 50 % at 23 °C

Quantity	Description	Estimate	Uncertainty or half-width	Standard uncertainty	Distribution	Divisor	Sensitivity coefficient	Uncertainty contribution
U_S	Mean value of corrected reading of the standards	52.2 %	0.04 %	0.04 %	normal	1	1.0	0.04 %
$\delta U_{cal,S1}$	Calibration standard 1	0.0 %	0.6 %	0.3 %	normal	2	0.5	0.15 %
$\delta U_{cal,S2}$	Calibration standard 2	0.0 %	0.6 %	0.3 %	normal	2	0.5	0.15 %
$\delta U_{drift,S1}$	Drift standard 1	0.0 %	1.0 %	0.58 %	rectangular	√3	0.5	0.29 %
$\delta U_{drift,S2}$	Drift standard 2	0.0 %	1.0 %	0.58 %	rectangular	√3	0.5	0.29 %
$\delta U_{res,1}$	Resolution standard 1	0.0 %	0.05 %	0.03 %	rectangular	√3	0.5	0.01 %
$\delta U_{res,2}$	Resolution standard 2	0.0 %	0.05 %	0.03 %	rectangular	√3	0.5	0.01 %
$\delta U_{int,S1}$	Interpolation between calibration points standard 1	0.0 %	0.25 %	0.14 %	rectangular	√3	0.5	0.07 %
$\delta U_{int,S2}$	Interpolation between calibration points standard 2	0.0 %	0.25 %	0.14 %	rectangular	√3	0.5	0.07 %
$\delta U_{hys,S1}$	Hysteresis standard 1	0.0 %	0.00 %	0.00 %	rectangular	√3	0.5	0.00 %
$\delta U_{hys,S2}$	Hysteresis standard 2	0.0 %	0.00 %	0.00 %	rectangular	√3	0.5	0.00 %
$\delta U_{i,S1-2}$	Difference between standards	0.0 %	0.00 %	0.00 %	rectangular	√3	1.0	0.00 %
δU_{Tdep}	Temperature dependence humidity measurement	0.0 %	0.35 %	0.20 %	rectangular	√3	1.0	0.20 %
δT_{htd}	Heat dissipation	0.0 %	0.0 K	0.00 K	rectangular	√3	3.16 %/K	0.00 %
δT_{sht}	Self-heating	0.0 %	0.1 K	0.06 K	rectangular	√3	3.16 %/K	0.18 %
$U_{i,X}$	Indication climatic chamber humidity	49 %	0.24 %	0.24 %	normal	1	1.0	0.24 %
δU_{inhom}	Local humidity inhomogeneity Measuring location	0.0 %	0.6 %	0.35 %	rectangular	√3	1.0	0.35 %
δU_{instab}	Humidity instability	0.0 %	0.5 %	0.29 %	rectangular	√3	1.0	0.29 %
δU_{load}	Loading influence	0.0 %	0.45 %	0.26 %	rectangular	√3	1.0	0.26 %
$\delta U_{res,X}$	Resolution	0.0 %	0.5 %	0.29 %	rectangular	√3	1.0	0.29 %
ΔU_X	Deviation of the indication	-3.2 %					u = 1.16 %	

The expanded measurement uncertainty for the calibration of the indication for the relative humidity in the climatic chamber in relation to the measuring location is: $U = k \cdot u(\Delta \mathrm{U_X}) = 2 \cdot 1.16\ \% \cong 2.4\ \%$.

If in this budget a rectangular contribution, e.g. inhomogeneity or similar, clearly outweighs all other contributions, a coverage factor $k \neq 2$ is to be applied for a coverage probability of approximately 95 %, because the measurement uncertainty is then not based on a normal distribution.

Since in this example several rectangular contributions of almost the same order of magnitude contribute to the combined total measurement uncertainty, a normal distribution can be approximately assumed here, and the coverage factor can be assumed to be $k = 2$.

With the effective degrees of freedom for the standard measurement uncertainty of the result being too small, a coverage factor $k > 2$ may also result.

Appendix B1 Example of a certificate for calibrations according to method (A) or (B) (Variant 1)

Measurement results

Gas temperature:

Controller setting relative humidity in %	Controller setting temperature in °C	Temperature standard at reference location in °C	Temperature indication calibration item in °C	Deviation of the indication in K	Measurement uncertainty in K

Gas humidity:

Controller setting temperature in °C	Controller setting relative humidity in %	Relative humidity standard at reference location in %	Indication of relative humidity calibration item in %	Deviation of the indication relative humidity in %	Measurement uncertainty relative humidity in %

Further investigation results

Spatial distribution:

Controller setting relative humidity	Controller setting temperature	Temperature standard thermometer								
		1	2	3	4	5	6	7	8	9 Reference location
in %	in °C	in °C	in °C	in °C	in °C	in °C	in °C	in °C	in °C	in °C

Controller setting temperature	Controller setting relative humidity	Relative gas humidity								
		1	2	3	4	5	6	7	8	9 Reference location
in °C	in %	in %	in %	in %	in %	in %	in %	in %	in %	in %

Results for the characterisation of the useful volume:

Temperature					
Controller setting relative humidity in %	**Controller setting temperature in °C**	**Inhomogeneity in K**	**Instability in K**	**Radiation influence in K**	**Loading influence in K**

Relative humidity				
Controller setting temperature in °C	**Controller setting relative humidity in %**	**Inhomogeneity in %**	**Instability in %**	**Loading influence in %**

The measured temperature and humidity values are mean values from repeated measurements. The gas temperatures stated were determined using a thermometer with an emissivity of $\varepsilon < 0.15$. The remaining radiation effect was not corrected but taken into account in the stated measurement uncertainty. The specified contributions to the characterisation of the volume represent the maximum variation ranges of the temperature or humidity under the specified measurement conditions. The calibration was carried out in air.

The stated results only apply to the useful volume of the climatic chamber spanned by the measuring locations. All other parts of the interior volume are not considered calibrated.

The measurement results apply to the condition of the calibration item listed above at the time of calibration and only for the specified calibration points.

The gas temperature and gas humidity result from the relationships:

gas temperature = temperature indication – indication deviation

gas humidity = humidity indication – indication deviation

Please also refer to the information on the use of climatic chambers on the information sheet enclosed.

Measurement uncertainty

The measurement uncertainties for the temperatures and relative humidities have been determined from the uncertainties of the calibration of the standards, the measurement methods used and the investigated properties of the climatic chamber. The uncertainty stated is the expanded measurement uncertainty which results from the standard measurement uncertainty multiplied by the coverage factor $k = 2$. It has been determined in accordance with EA-4/02 M: 2022. The value of the measured quantity lies within the assigned value interval with a probability of approximately 95 %.

Appendix B2 Example of a certificate for calibrations according to method (A) or (B) (Variant 2)

Measurement results

Controller setting	Indication calibration item	Temperature / relative humidity of the standard at reference location	Deviation of the indication	Indication correction	Measurement uncertainty
25.0 °C					
97.0 %					
40.0 °C					
93.0 %					
55.0 °C					
20.0 %					
85.0 °C					
85.0 %					

Further investigation results: spatial distribution

Controller setting	Temperature standard thermometer / relative humidity standard hygrometer								
	1 (reference location)	2	3	4	5	6	7	8	9
25.0 °C									
97.0 %									
40.0 °C									
93.0 %									
55.0 °C									
20.0 %									
85.0 °C									
85.0 %									

Results for the characterisation of the useful volume:

Controller setting	Inhomogeneity	Instability	Radiation influence	Loading influence
25.0 °C				
97.0 %				
40.0 °C				
93.0 %				
55.0 °C				
20.0 %				
85.0 °C				
85.0 %				

The measured temperature and humidity values are mean values from multiple measurements. The gas temperatures stated were determined using a thermometer with an emissivity of $\varepsilon < 0.15$. The remaining radiation effect was not corrected but taken into account in the stated measurement uncertainty. The specified contributions to the characterisation of the volume represent the maximum variation ranges of the temperature or humidity under the specified measurement conditions. The calibration was carried out in air.

The specified results only apply to the useful volume of the climatic chamber spanned by the measuring locations. All other parts of the interior volume are not considered calibrated.

The measurement results apply to the condition of the calibration item listed above at the time of calibration and only for the specified calibration points.

The gas temperature and gas humidity result from the relationships:

gas temperature = temperature indication – indication deviation
gas humidity = humidity indication – indication deviation

Please also refer to the information on the use of climatic chambers on the information sheet enclosed.

Measurement uncertainty

The measurement uncertainties for the temperatures and relative humidities have been determined from the uncertainties of the calibration of the standards, the measurement methods used and the investigated properties of the climatic chamber. The uncertainty stated is the expanded measurement uncertainty which results from the standard measurement uncertainty multiplied by the coverage factor $k = 2$. It has been determined in accordance with EA-4/02 M: 2022. The value of the measured quantity lies within the assigned value interval with a probability of approximately 95 %.

Appendix B3 Example of a certificate for calibration according to method (D)

Measurement results

Controller setting	Indication calibration item	Temperature of standard at reference location	Deviation of the indication	Indication correction	Measurement uncertainty
25.0 °C					
40.0 °C					

Further investigation results: spatial distribution

Controller setting	Temperature standard thermometer		
	1 (reference location)	2	3
25.0 °C			
40.0 °C			

Results for the characterisation of the useful volume:

Controller setting	Inhomogeneity	Instability	Radiation influence	Loading influence
25.0 °C				
40.0 °C				

The temperature values are mean values from multiple measurements. The gas temperatures stated were determined using a thermometer with an emissivity of $\varepsilon < 0.15$. The remaining radiation effect was not corrected but taken into account in the specified measurement uncertainty. The specified contributions to the characterisation of the useful volume represent the maximum variation ranges of the temperature under the specified measurement conditions. The calibration was carried out in air.

The results stated apply only to the useful volume of the climatic chamber which is defined by the diagonally arranged measuring locations (body diagonal). The arrangement of the sensor positions in the useful volume is shown in the sketch. All other parts of the interior volume are not considered calibrated.

The measurement results apply to the condition of the calibration item listed above at the time of calibration and only for the specified calibration points.

The gas temperature results from the relationship:

gas temperature = temperature indication – indication deviation

Please also refer to the information on the use of climatic chambers on the information sheet enclosed.

Measurement uncertainty
The measurement uncertainties for the temperatures and relative humidities have been determined from the uncertainties of the calibration of the standards, the measurement methods used and the investigated properties of the climatic chamber. The uncertainty stated is the expanded measurement uncertainty which results from the standard measurement uncertainty multiplied by the coverage factor $k = 2$. It has been determined in accordance with EA-4/02 M: 2022. The value of the measured quantity lies within the assigned value interval with a probability of approximately 95 %.

Appendix C Example of a calibration certificate for calibration of a measuring location according to method (C)

Measurement results

Gas temperature:

Controller setting relative humidity in %	Controller setting temperature in °C	Temperature of standard at measuring location in °C	Temperature indication calibration item in °C	Deviation of the indication in K	Measurement uncertainty in K

Gas humidity:

Controller setting temperature in °C	Controller setting relative humidity in %	Relative humidity of standard at measuring location in %	Indication relative humidity calibration item in %	Deviation of the indication relative humidity in %	Measurement uncertainty relative humidity in %

Further investigation results for the characterisation of the conditions in the measuring location:

Temperature controller setting relative humidity in %	Controller setting temperature in °C	Local inhomogeneity in K	Instability in K	Radiation influence in K	Loading influence in K

Relative humidity controller setting temperature in °C	Controller setting relative humidity in %	Local inhomogeneity in %	Instability in %	Loading influence in %

The measured temperature and humidity values are mean values from multiple measurements. The specified gas temperatures were determined using a thermometer with an emissivity of $\varepsilon < 0.15$. The remaining radiation effect was not corrected but taken into account in the specified measurement uncertainty. The specified contributions for characterising the conditions at the measurement location represent the maximum variation ranges of the temperature or humidity under the specified measurement conditions.
The calibration was carried out in air.

The specified results only apply to the measuring location or the volume of a cube with a maximum edge length of 5 cm, in the centre of which the measuring location is located. All other parts of the interior volume are not considered calibrated.

The measurement results apply to the condition of the calibration item listed above at the time of calibration and only for the specified calibration points.

The gas temperature or gas humidity at the measuring location is calculated according to the relationships:

gas temperature = temperature indication – indication deviation
gas humidity = humidity indication – indication deviation

Please also refer to the information on the use of climatic chambers on the information sheet enclosed.

Measurement uncertainty

The measurement uncertainties for the temperatures and relative humidities have been determined from the uncertainties of the calibration of the standards, the measurement methods used and the investigated properties of the climatic chamber. The uncertainty stated is the expanded measurement uncertainty which results from the standard measurement uncertainty multiplied by the coverage factor $k = 2$. It has been determined in accordance with EA-4/02 M: 2022. The value of the measured quantity lies within the assigned value interval with a probability of approximately 95 %.

Appendix D Supplement to the calibration certificate for climatic chambers

Notes on the calibration and use of climatic chambers

General information

Without further details in the calibration certificate, the calibration is valid only for the gas temperature and/or gas humidity in the empty useful volume of the climatic chamber.
If measuring conditions other than those specified are used, considerable deviations from the calibration value (up to several Kelvin) are to be expected in some cases.

Radiation influences

When using the climatic chambers in a temperature range above room temperature, the walls of many models have a lower temperature than the gas. Due to radiation losses, the gas temperature in these cases is higher than the temperature of a thermometer or test object in the useful volume.
Likewise, considerable temperature differences may occur between the temperature of the thermometer and the temperature of an object (→ "Object in useful volume") in the climatic chamber. This is especially the case if the emissivity or emittance (ε) of the object does not match that of the thermometer; in such cases large differences are to be expected.
Due to the law of radiation, the influence of this effect increases more than proportionally at higher temperatures. Below room temperature, the sign of the radiation effect is reversed but the effect is significantly smaller and often negligible.
Depending on the model of climatic chamber, differences of several Kelvin may be possible above 150 °C.

Objects in the useful volume

Objects in the useful volume will generally not assume the gas temperature that prevailed during calibration because

1) the conditions of loading - if not exactly reproduced during calibration - influence and change the temperature field in the useful volume,
2) the position, size and material of the object generally do not match the characteristics of the thermometer used to calibrate the climatic chamber, and
3) the object is qualitatively, but not quantitatively, subject to comparable → radiation influences, as is the case with a thermometer.

Relative humidity in the useful volume

The distribution of the relative humidity in the useful volume can be significantly altered if there are sources or sinks for water vapour in the useful volume, if effective mixing of the useful volume is not guaranteed or if the exchange of gas with the environment may occur due to leaks.

Measurement uncertainty

The measurement uncertainty stated only applies if the documented measurement conditions are complied with. It applies to the temperature or humidity indication of the climatic chamber in relation to the temperature or relative humidity of the gas in the climatic chamber at a defined position or for a defined volume.
Reproducing the calibration value within the stated uncertainty is only possible with the same loading condition, measuring point(s) or useful volume and similar thermometer properties ($\varepsilon < 0.2$).
The radiation effect of the standard used, in relation to the climatic chamber calibrated here, has been determined and taken into account in the measurement uncertainty. A correction of the effect has not been made, unless it is explicitly stated in the calibration certificate.

Appendix E Additional information for the use of climatic chambers in the context of metrological traceability

When using climatic chambers in testing or calibration procedures, the calibration of the climatic chambers is carried out to fulfil the requirements for metrological traceability.
The requirements to be applied here

- calibration interval and calibration methods
- calibration points and scope of calibration
- evaluation criteria

arise from the requirements of the testing or calibration procedure and, in particular, from the risk assessment and the effects of deviations greater than the applied measurement uncertainty for the respective application.
Generally applicable specifications cannot be made here! However, the applicable guidelines of the DKD-R-5 series are to be observed.

In principle, the following applies:

- The demands for traceability of the climatic chamber as a whole can be dispensed with if gas temperature and gas humidity are measured during testing/calibration at the testing/calibration site (in situ) using traceable thermometers and hygrometers. In this case, however, the essential contributions to the measurement uncertainty that are otherwise included in the calibration must be additionally determined and taken into account (inhomogeneity, instability, radiation, loading, …). It is therefore advisable to use a measuring system with a sufficient number of thermometers (determination of inhomogeneity) and time resolution (determination of instability) as well as an appropriate emissivity. Suitable proof/verification can then be defined by the user. Guidance on determining the scope and the number of repetitions can be found in the relevant chapters of this guideline. This approach is particularly recommended when large areas, strongly varying loads or similar are present.

- For characterisation, the requirements laid down in DKD-R 5-1 and DKD-R 5-8 are to be taken into account.

- If traceability as a whole is required, then the method of reducing the useful volume to a fraction of the inner volume, possibly with the use of additional radiation shields and air guiding devices, often represents a way to increase the stability and reproducibility of the conditions in the useful volume. All points of the guideline are fully applicable to this adjusted useful volume. The generally resulting reduction of the measurement uncertainty contributions leads to an increase in the reproducibility and stability of the calibration results and subsequently facilitates risk assessment.

- Prolongation of traceability or inspection intervals always require the proof of reliability and the monitoring of compliance with the underlying requirements. In this context, methods such as intermediate tests, proficiency tests and comparison measurements as well as further quality assurance measures, if necessary, are to be applied. Calibrations according to method (C) at the reference measuring location and at least at the respective measuring location where the extreme contributions to the measurement uncertainty were found during calibration according to method (A), (B) or (D) can, for example, be useful intermediate tests here. In doing so, at least the calibration points with the greatest deviation from the admissible ambient conditions (maximum and minimum) are to be examined. A risk assessment is required!

- With regard to the effects of possible drifts in the climatic chamber’s internal temperature and humidity measurement technology, the requirements from the respective calibration guidelines for thermometers and hygrometers are to be observed.

The user (testing or calibration laboratory) is responsible for establishing appropriate and verifiable regulations based on their risk assessments.

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