Thai Laboratory Accreditation Scheme

Publication Reference G-20

Guidelines for Calibration and Checks of Temperature Controlled Enclosures

Contents

Purpose

This document has been published by TLAS to improve the harmonization in calibration and performance survey of temperature controlled enclosures. It describes procedures for measuring such characteristics: temperature uniformity, stability and indicating accuracy within the working volume. The procedure applies to the unloaded condition under steady state mode of operation.

0 Scope

0.1 This guideline sets out a procedure for the calibration of the temperature indicating device of temperature-controlled enclosures by comparison of the indication with the temperature measured by the standards at specified locations inside the working space of chamber.

0.2 The guideline applies solely to the determination of such characteristics at the unloaded condition and at steady-state operation. It does not apply to other enclosure parameters such as humidity, airflow and others that may be controlled.

0.3 The procedure is for measuring temperature uniformity, stability, overall variation and indicating accuracy at temperature range of -90 °C to 500 °C and is applicable to all air or gas filled temperature controlled enclosures at atmospheric pressure, equipped with automatically temperature controlling system and indicating device, regardless of chamber size, method of construction, type or purpose.

0.4 According to the way of use, the calibration and performance survey of temperature-controlled enclosures can be done at specific positions, locations and temperature set points within the chamber. It is the user's responsibility to ensure that the performance of chamber being determined can be achieved in the correct manner.

1 Definitions

1.1 *Temperature Uniformity* - the maximum difference of measured temperatures at any sensors and the measured temperature at the reference location which are observed at the same time or at as close an observation time as possible to determine the temperature pattern or homogeneity within the chamber under steady state conditions. The reference sensor should preferably be located at the geometric center of the chamber.

1.2 *Temperature Stability* - one-half of the greatest maximum difference of measured temperatures at any one sensor, for at least half an hour after reaching steady state or after one achieved complete cycle of control whichever comes first. The specific check of temperature stability at specific positions or locations of working space within the chamber according to the way of use should be specified.

Note: A continuous record of measured temperature is preferable and if not possible, that recorded data should be able to determine the temperature pattern or stability within the chamber under steady state conditions.

1.3 *Overall Variation* – the difference of the maximum and the minimum measured temperatures throughout observation time.

1.4 *Indicating Temperature* - the average reading of indicating device that forms the integral part of the enclosure. If the enclosure is equipped with only setting device, the setting temperature can be considered as indicating temperature.

1.5 *Measured Temperature* - the average reading of standards at any positions or locations.

1.6 *Specific Check* – calibration performed at any specific measuring positions or locations within the working space which deviates from the general procedure.

1.7 *Working Space* - three-dimensional region inside the chamber around which the standard sensors are located.. The calibration is only valid for the working space covered by standard sensors located that meets the requirements of the guidelines.

1.8 *Steady State* - The stable situation, when temperature at reference location is set and achieved after:-

- 5 complete cycles but not less than one hour of operation time or
- 1 hour of operation time.

2 Introduction

2.1 This guideline sets out a procedure for calibration and temperature checks of atmospheric pressure enclosures, for use in laboratories throughout industry, at unloaded condition, under steady state operation and regardless of size. No account is taken of other characteristics, i.e. time constant, rate of ventilation and other parameters i.e. humidity.

2.2 This technical guideline has been produced to assist laboratories wishing to carry out temperature checks as a preferred method to determine the enclosure performance required by TLAS. For further information, other relevant documents and standards can be found in the references.

2.3 The temperature-controlled enclosure shall be calibrated as a system with its sensing and indicating device in place and operating as in actual use. System verification is invalid if the devices are removed and checked independently of the enclosure.

2.4 The extrapolation calibration of temperature-controlled enclosure is not acceptable.

3 Reference Equipment Requirements

3.1 The guideline recommends that the standard equipment used should have capability to show variation of working space temperature. The standard should normally be composed of two parts; temperature sensors such as resistance temperature detector (RTD) or thermocouples or others and indicating device such as thermometer, data logger, recorder etc.

Note: The standard equipment is preferably required to be such that the total measurement uncertainty should not be greater than one-third of the required accuracy of the indicating device or uniformity or stability or overall variation or other specified limits of the enclosure.

3.2 A set of temperature sensors should be used that has properties suitable for checking chamber temperatures and which covers the required calibration range. It may be RTD or thermocouples. All sensors should be flexible for convenient installation. The wire insulation and any means of sensor support such as material, size and location should have minimal effect to the responses of sensors. They should have enough length and proper characteristics to avoid stem conduction loss and measurement delays due to thermal response times.

3.3 The response time of the measuring equipment should be consistent with the characteristics of the chamber that are required to be measured. If one standard indicator or recorder is capable of being equipped with multiple sensors, each one should be connected to the channels as calibrated to reflect or record the correct temperature. To avoid time lagging effect, all indicators should be as identical as possible and this will be also applicable to the temperature sensors.

3.4 The number of standard sensors required is related to the volume of the working space to be calibrated. Not less than nine sensors are required for calibration of chamber capacity of 1 m^3 or less. For larger chambers, the distance between any sensor and the adjacent one should not exceed 100 cm. At least 2 sensors are required for specific check; one is the reference sensor located at the reference position and the other is a check sensor, which should be located within 5 cm of the reference sensor.

Note: see Figures 1, 2, 3 and 4 (examples of sensor installation location and diagrams)

3.5 The minimum number of measuring sensors for calibration of the working space of a chamber volume of 1 m^3 or smaller is nine sensors at nine locations as shown in Figure 1. All sensors at any corners or walls should be positioned between 5 cm and 10 cm from the wall. The reference sensor is preferably located within ±2.5 cm of the geometric center of the chamber.

4 Calibration Procedure

4.1 Preliminary Check

a) Prior to commencing the calibration work, visual checks of the enclosure, sealing and its associated equipment should be performed to meet full operational conditions. Any deficiencies found should be recorded and evaluated to ensure that they do not affect the enclosure performance.
b) All characteristics of the enclosure such as degree of venting, relative heater powers and others should be adjusted to be their usual settings for normal working conditions. If any deviations have occurred, those different settings shall be recorded.
c) The enclosure should be operated in an unloaded condition however any normal integral parts or accessories should be in their usual positions.
d) Throughout the calibration process period, the ambient temperature at approximately 2 m around the enclosure shall be monitored and recorded. The temperature variations should not exceed 10°C. If the varied temperature is more than 10°C, it should be ensured that this variation does not significantly affect the inside chamber temperature. The line voltage supplied to the enclosure shall be also recorded and it should not vary more than 10 %, or as otherwise specified by the manufacturer.

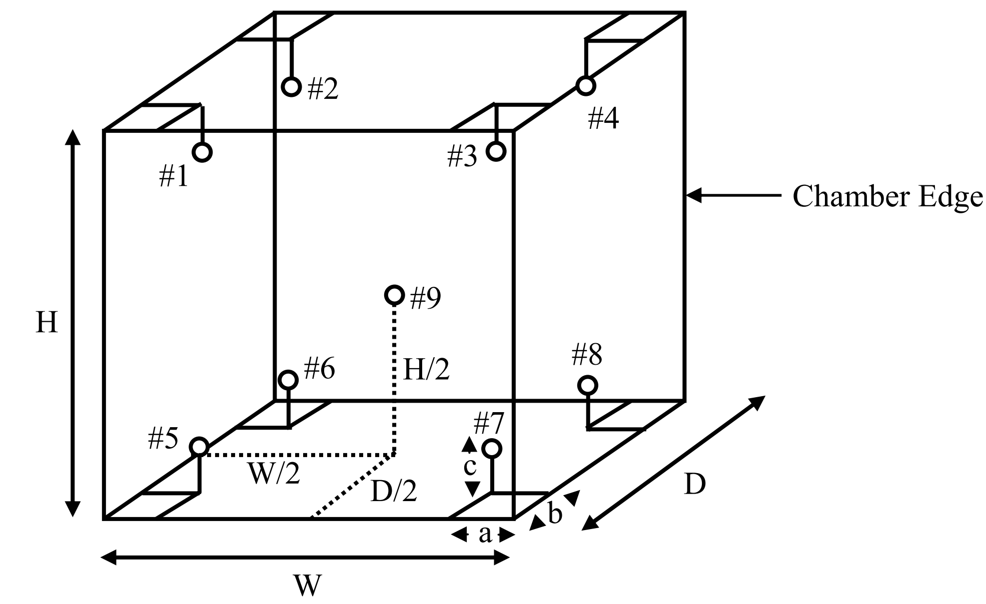
4.2 Temperature Sensor Installation

The calibration is performed for the working space spread by the measuring sensors and covered all locations required. All standard sensors are placed in the unloaded chamber and one sensor should be located at each corner and wall at approximately 5 cm to 10 cm away from the walls as shown below.

For other shapes of design, i.e. cylindrical or spherical chamber, the sensor installation can be done in the same manner as in the rectangular or cubical chamber. See Figures 1, 2, 3 and 4 (examples of sensor installation location and diagrams)

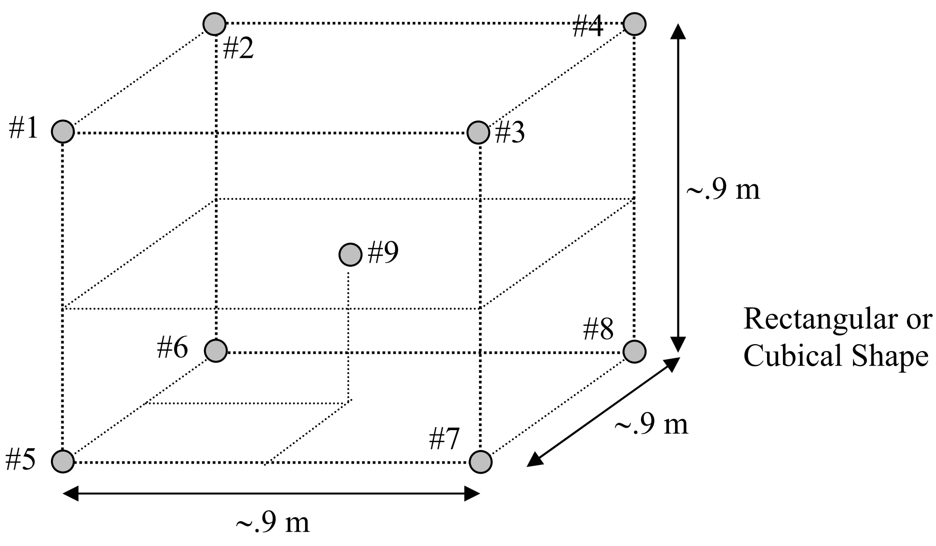
Note: If the installation of standard sensors cannot be done as mentioned above, the deviation should be identified and recorded. For chambers with capacity larger than 1 m^3, the distance between the standard sensors installed should be symmetrical and the distance between adjacent sensors should not exceed 100 cm.

Sensor Installation



<u>Figure 1: Sensor Installation Locations</u>

(For 1 m^3 chamber and smaller)



<u>Figure 2: Sensor Installation Diagram</u>

(Working space for 1 m^3 chamber)

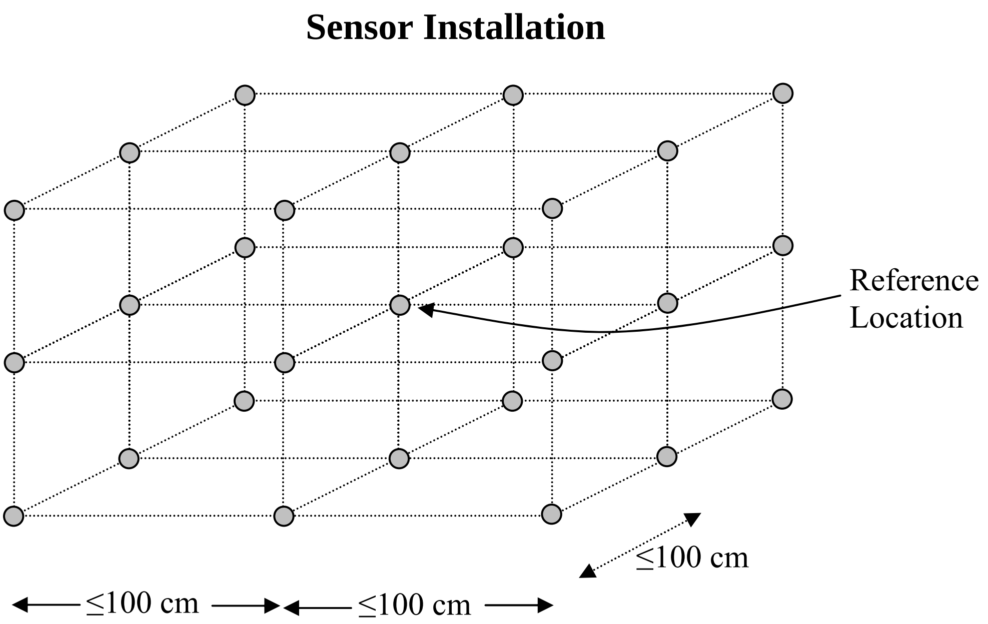


Figure 3: Sensor Installation (for ≥1 m^3 chamber)

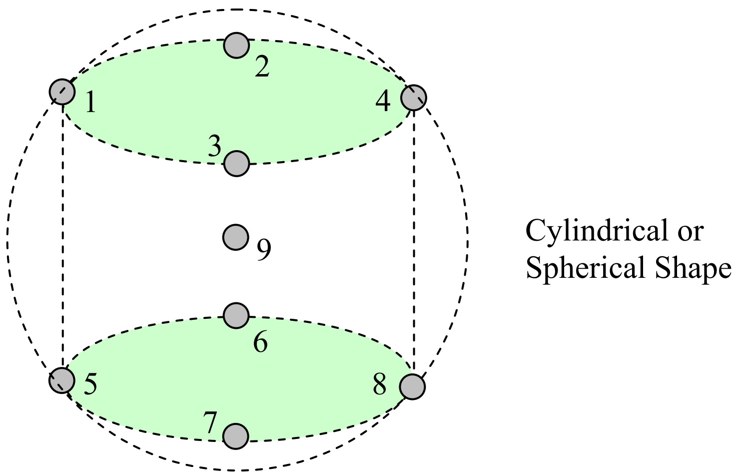


Figure 4: Sensor Installation for other chamber shapes

4.3 Calibration

The enclosure should be set and operated at the specified temperature and allowed to reach steady state conditions before proceeding to the next step of measurement recording.

The temperature readings of the chamber and of all standard sensors should be recorded simultaneously. The recording interval shall commence after steady state has been achieved and shall be a sufficient period of time to characterize or determine the stability. A graphical record is preferable.

To confirm the enclosure performance and usage temperature range, a check of an enclosure at a single temperature is not recommended. These guidelines recommend that the chambers be calibrated at a minimum of two different temperatures. A single temperature check may be performed if specified by the customer, or if other technically valid reasons can be demonstrated.

4.4 Investigation of Enclosure Performance

a) The temperature uniformity and stability shall be calculated as in the definition. As part of the calibration for discrete points of the chamber according to specific checks, only uncertainty contributions based on the variation can be determined.

b) The raw data of indicating device and each sensor reading should be averaged. The correction of standard might be added individually for better accuracy; otherwise a component of uncertainty should be included in the uncertainty budget for uncorrected errors. The calculation data should be reported.

c) An example of the enclosure calibration and data recording using 9 sensors at a setting of 50 °C is shown below.

Record No.	Chamber Indicator (°C)	Standard Reading (°C)@ Sensor Number								(Ref)
		#1	#2	#3	#4	#5	#6	#7	#8	#9
1	50.0	50.5	50.3	49.0	50.3	49.5	51.0	50.7	49.0	49.5
2	50.0	51.0	50.0	48.5	50.5	50.0	50.7	50.3	48.5	49.7
3	50.0	51.3	49.5	49.1	51.0	50.2	50.0	50.3	49.1	50.0
4	50.0	50.5	49.0	49.7	49.8	50.5	49.2	50.0	49.7	50.2
5	50.0	50.0	48.5	50.3	49.5	51.0	48.0	49.0	50.3	50.0
6	50.0	49.5	48.0	50.5	50.0	50.7	47.5	48.5	50.5	49.7
7	50.0	49.0	47.5	51.0	50.2	51.0	47.4	49.1	51.0	49.4
8	50.0	48.5	48.0	49.8	50.5	51.6	48.8	49.7	49.8	49.5
9	50.0	49.1	49.0	49.5	51.0	50.8	49.0	50.3	49.5	49.8
10	50.0	49.7	50.1	50.0	50.7	50.2	48.5	50.5	50.0	50.0
11	50.0	50.3	51.0	50.2	50.5	50.5	49.1	51.0	50.2	50.3
12	50.0	50.5	51.5	50.5	51.0	49.8	49.7	49.8	50.5	50.5
13	50.0	51.0	50.8	51.0	50.7	49.0	50.3	49.5	51.0	50.7
14	50.0	49.8	50.2	50.7	50.3	48.2	50.5	50.0	50.7	50.3
15	50.0	49.5	50.5	50.5	50.3	47.8	51.0	50.2	50.5	49.9
16	50.0	50.0	49.8	51.0	50.0	49.7	49.8	50.5	51.0	49.5
17	50.0	50.2	49.0	50.7	49.0	50.3	49.5	51.0	50.7	49.0
18	50.0	50.5	48.2	50.3	48.5	50.5	50.0	50.7	50.3	49.5
19	50.0	51.0	47.8	50.3	49.1	51.0	50.2	50.5	50.3	49.7
20	50.0	50.7	48.5	50.0	49.7	49.8	50.5	51.0	50.0	50.0
Mean	50.0	50.1	49.4	50.1	50.1	50.1	49.5	50.1	50.1	49.9

The temperature uniformity defined in (1.1) is calculated for the different temperature of record number 6, sensor number 6 and 9;

Chamber Uniformity = (49.7-47.5) °C
= 2.2 °C

The temperature stability defined in (1.2) is calculated for one half of the different temperature of sensor number 2, record number 7 and 12;

Chamber Stability = (51.5-47.5)/2 °C
= ±2.0 °C

The overall variation defined in (1.3) is calculated for the difference of measured temperature of sensor number 5 (record number 8) and measured temperature of sensor number 6 (record number 7);

Overall Variation = (51.6-47.4) °C
= 4.2 °C

5. Reporting of the Results

Each test report, test certificate, calibration report or calibration certificate shall include at least the following information; unless the laboratory has exceptional reasons for not doing so:

a) Name and address of the customer placing the order;
b) Description, condition and unambiguous unique identification of the item being calibrated together with manufacturer, model, serial number and/or other necessary information;
c) Date of receipt of calibration item and date of verification or calibration where relevant to the validity and application of the results;
d) The ambient conditions (e.g. temperature) with value of ac power line voltage of the chamber under which the calibrations were made;
e) Identification of the standardized test method(s) used, or unambiguous brief description of any non-standardized method used;
f) Deviations from, additions to or exclusions from the calibration method, and information on specific calibration conditions, such as environmental conditions;
g) Calibration results with detailed investigation results and the uncertainty of calibration and/or a statement of compliance with an identified metrological specification according to the contract/agreement with customer. The results may be in graphical format with detail of installation over calibration volume or measuring location(s)/position of sensors (drawing of geometric distribution of sensors and/or numerical);
h) The confidence level of the expanded uncertainty;
i) Evidence or statement of the measurement traceability;
j) Additional information which is required by ISO/IEC 17025 clause 5.10.

Example for reporting of temperature distribution

Indicating Temperature (°C)	Measured Temperature (°C) @ Sensor No. (Sensor No.9 is REF)									Uncertainty ±°C
	#1	#2	#3	#4	#5	#6	#7	#8	#9	
0										
100										
200										
300										

Example for Reporting of Chamber Performance

Setting Temperature (°C)	Indicating Temperature (°C)	Measured Uniformity (°C)	Measured Stability (°C)	Overall Variation (°C)
0				
100				
200				
300				

6. Uncertainty Contributions

The measurement uncertainty stated is valid for both general calibration and specific checks. The measurement uncertainty stated is the expanded uncertainty, which is obtained from the standard uncertainty, multiplied by the coverage factor (k = 2) to provide a level of confidence of approximately 95%. It is determined in accordance with the Guide to Expression of Uncertainty in Measurement (GUM) or EA-4/02: Expression of the Uncertainty of Measurement in Calibration.

Mathematical Model

$\Delta T_{Chamber} = T_{Std} - T_{Ind} + \delta T_{Rep\_UUC} + \delta T_{Std} + \delta T_{Stab} + \delta T_{Load} + \delta T_{Res\_UUC} + \delta T_{Rad}$
and $\delta T_{Std} = \delta T_{Cal\_Std} + \delta T_{Drift\_Std} + \delta T_{Res\_Std} + \delta T_{Stem\_Std} + \delta T_{Self\_Heat}$

where;

- $\Delta T_{Chamber}$ is the correction of the reading of indicating device;
- T_{Std} is the temperature at related measurement locations;
- T_{Ind} is the temperature of the indicating device;
- δT_{Cal_Std} is the imported uncertainty of standard thermometers;
- δT_{Drift_Std} is the drift of standard thermometers;
- δT_{Res_Std} is the resolution of standard thermometers;
- δT_{Stem_Std} is the stem or heat conduction effect of sensor;
- δT_{Self_Heat} is the different temperature of RTD sensor, where used, due to heat transferring difference of media during calibration and use;
- δT_{Rad} is the wall radiation effect according to various sensor constructions;
- δT_{Rep_UUC} is the repeatability of temperature indicating device of the chamber;
- δT_{Stab} is the stability of measurement or repeatability of standard;
- δT_{Load} is the loading effect due to standard and accessories;
- δT_{Res_UUC} is the setting ability of chamber and/or resolution of temperature indicating device of the chamber.

6.1 The calibration certificate for standard thermometer is given an imported uncertainty, δT_{Cal_Std}, with temperature unit, K or °C, at a level of confidence of approximately 95 % ($k = 2$).

6.2 The change in measurement values of standard thermometer with time was estimated as long term drift, δT_{Drift_Std}, from history records and previous calibration with units of K or °C. The probability distribution is rectangular.

6.3 The least significant digit or resolution of reference thermometers, δT_{Res_Std}, is indicated in K or °C and the rounding has limit of $0.5\delta T_{Res\_Std}$ with rectangular distribution.

6.4 The heat conduction effect of standard sensors due to immersion effects, δT_{Stem_STD}, is examined from previous knowledge when being immersed at various depths. The temperature unit is in K or °C and the distribution is rectangular.

6.5 When RTD sensors are selected as standard, the heat transferring effect due to different media (when calibrated and used), δT_{Self_Heat} is contributed with unit in K or °C and the distribution is rectangular.

6.6 The repeatability of unit under calibration (UUC), δT_{Rep_UUC}, is calculated from series of chamber indicating temperature that gives standard deviation in K or °C, with normal distribution.

Note: If there is no reading indicator equipped to the chamber, this contribution will be negligible.

6.7 The stability of enclosure calibration at temperature point, δT_{Stab}, is calculated in step 4.4.b) and units in K or °C, with a rectangular distribution. The repeatability of measured temperature of standard sensor (at worst case) can be substituted with unit in K or °C and normal distribution.

6.8 The loading effect due to standard and its accessories, δT_{Load}, is being estimated to be no-load condition by adding 20% of uniformity ($0.2\delta T_{Uniform}$) unit in K or °C with rectangular distribution.

6.9 The enclosure setting ability or resolution of temperature indicating device of the enclosure, δT_{Res_UUC}, is established in K or °C. the rounding has limit of $0.5\delta T_{Res\_UUC}$ with rectangular distribution.

6.10 The standard sensors might indicate an incorrect value of temperature depending on their construction and the wall emissivity. The radiation effect during calibration due to emissivity of chamber walls and standard sensor constructions, δT_{Rad}, is estimated in K or °C, with a rectangular distribution.

Uncertainty Budget Table

Quantity	Symbol	Probability Distribution	Divisor	Sensitivity Coefficient	Standard Uncertainty	Degree of freedom or effective degree of freedom
Repeatability of UUC Indicator	$\delta T_{\text{Rep\_UUC}}$	Normal	1	1	$\delta T_{\text{Rep\_UUC}}$	Number* of readings – 1
Calibration of Standard	$\delta T_{\text{Cal\_Std}}$	Normal	k**	1	$\frac{\delta T_{Cal\_Std}}{k}$	υ_{eff}
Drift of Standard	$\delta T_{\text{Drift\_Std}}$	Rectangular	√3	1	$\frac{\delta T_{Drift\_Std}}{\sqrt{3}}$	∞
Resolution of Standard	$\delta T_{\text{Res\_Std}}$	Rectangular	√3	1	$\frac{\delta T_{Res\_Std}}{\sqrt{3}}$	∞
Stem Conduction of Standard	$\delta T_{\text{Stem\_STD}}$	Rectangular	√3	1	$\frac{\delta T_{Stem\_STD}}{\sqrt{3}}$	∞
Chamber Stability	δT_{Stab}	Rectangular	√3	1	$\frac{\delta T_{Stab}}{\sqrt{3}}$	∞
Loading Effect	$0.2\times\delta T_{\text{Uniform}}$	Rectangular	√3	1	$\frac{0.2\times\delta T_{Uniform}}{\sqrt{3}}$	∞
Resolution of UUC Indicator	$\delta T_{\text{Res\_UUC}}$	Rectangular	√3	1	$\frac{\delta T_{Res\_UUC}}{\sqrt{3}}$	∞
Radiation Effect	δT_{Rad}	Rectangular	√3	1	$\frac{\delta T_{Rad}}{\sqrt{3}}$	∞
					u_{c}	υ_{eff}

Remark

* : Number of readings may vary due to total number of reference thermometers and UUC

** : The coverage factor from certificate at approx. 95% CL, normally $k = 2$.

There may be further uncertainties to be considered depending on the type of sensors used. For example, the use of thermocouples means that reference junction temperature, parasitic voltages and cable inhomogeneity would have to be included. For resistance thermometers, self-heating effects may be significant.

7. References

7.1 AS2853 – 1986: Enclosures – Temperature – Controlled Performance Testing and Grading

7.2 ASTM E 145 – 94 (Reapproved 2001): Standard specification for Gravity – Convection and Forced – Ventilation Ovens

7.3 BAC – 5621 JUN2000: Temperature Control for Processing of Materials of Boeing Aircraft Company

7.4 DKD – R 5 – 7 MAY2004: Calibration of Climatic Chambers

7.5 EA-4/02 DEC1999: Expression of the Uncertainty of Measurement in Calibration

7.6 EA-10/08 OCT97: Calibration of Thermocouples.

7.7 GUM 1995-Guide to the Expression of Uncertainty in Measurement by the International Organization for Standardization

7.8 ISO/IEC17025 2005: General Requirements for The Competence of Testing and Calibration Laboratories

7.9 NATA Technical Note No. 12 JUN1991: Measurement of Temperature Variation and Recovery Time in Laboratory Drying Ovens

8. Appendix A: Example of Temperature Controlled Enclosure Calibration and Reporting

8.1 The Measurement

A temperature controlled enclosure with 1 m^3 volume and usable temperature range of 20 °C to 150 °C, has been calibrated by comparing with a precision calibrated digital thermometer with 10-channel scanner and 9 platinum resistance thermometer sensors connected. The eight sensors were placed at the corners and approximately 50 mm away from the walls. The reference sensor was placed at the center of the working space in the temperature-controlled chamber over the range of 20 °C to 150 °C. The resolution of the indicating and setting point is 0.1 °C. For the following example, the indicating accuracy and temperature-controlled enclosure's characterization at 50 °C were considered.

8.2 The Model

The aim in calibration is to obtain the correction *C*:

$$C = \Delta t_X = t_S - t_X \qquad (1)$$

where t_S is the `true' temperature (°C) derived from the calibrated reference sensor (corrected for its calibration) and t_X is the value of temperature (°C) given for the enclosure indicator.

8.3 The Observations:

After operation of enclosure for an hour after steady state mode, the measurement data are stored and shown below. All recording data cover one or more full controlling cycle time.

Record No.	Chamber Indicator (°C)	Standard Reading (°C)@ Sensor Number								(Ref)
		#1	#2	#3	#4	#5	#6	#7	#8	#9
1	50.0	50.5	50.3	49.0	50.3	49.5	51.0	50.7	49.0	49.5
2	50.0	51.0	50.0	48.5	50.5	50.0	50.7	50.3	48.5	49.7
3	50.0	51.3	49.5	49.1	51.0	50.2	50.0	50.3	49.1	50.0
4	50.0	50.5	49.0	49.7	49.8	50.5	49.2	50.0	49.7	50.2
5	50.0	50.0	48.5	50.3	49.5	51.0	48.0	49.0	50.3	50.0
6	50.0	49.5	48.0	50.5	50.0	50.7	47.5	48.5	50.5	49.7
7	50.0	49.0	47.5	51.0	50.2	51.0	47.4	49.1	51.0	49.4
8	50.0	48.5	48.0	49.8	50.5	51.6	48.8	49.7	49.8	49.5
9	50.0	49.1	49.0	49.5	51.0	50.8	49.0	50.3	49.5	49.8
10	50.0	49.7	50.1	50.0	50.7	50.2	48.5	50.5	50.0	50.0
11	50.0	50.3	51.0	50.2	50.5	50.5	49.1	51.0	50.2	50.3
12	50.0	50.5	51.5	50.5	51.0	49.8	49.7	49.8	50.5	50.5
13	50.0	51.0	50.8	51.0	50.7	49.0	50.3	49.5	51.0	50.7
14	50.0	49.8	50.2	50.7	50.3	48.2	50.5	50.0	50.7	50.3
15	50.0	49.5	50.5	50.5	50.3	47.8	51.0	50.2	50.5	49.9
16	50.0	50.0	49.8	51.0	50.0	49.7	49.8	50.5	51.0	49.5
17	50.0	50.2	49.0	50.7	49.0	50.3	49.5	51.0	50.7	49.0
18	50.0	50.5	48.2	50.3	48.5	50.5	50.0	50.7	50.3	49.5
19	50.0	51.0	47.8	50.3	49.1	51.0	50.2	50.5	50.3	49.7
20	50.0	50.7	48.5	50.0	49.7	49.8	50.5	51.0	50.0	50.0
Mean	50.0	50.1	49.4	50.1	50.1	50.1	49.5	50.1	50.1	49.9

8.4 Uncertainty Contribution of the Standards/Reference Temperature

a) Calibration of Standard Thermometer:

The digital thermometer calibration uncertainty corresponding to term of temperature was ± 0.20 °C over the range 0 °C to 420 °C and the calibration was done at an ambient temperature of 23 °C ± 2 °C. The standard uncertainty (*Ui*) is ±0.10 °C with stated coverage factor, $k_{95} = 2.0$ and $\nu_{eff} = \infty$ from the Student *t*-distribution table.

b) Drift of Standard Thermometer:

The drift of digital thermometer over calibration period of using corresponding to temperature was 0.2 °C and the rectangular distribution is considered. The standard uncertainty (U_i) is ±0.12 °C with coverage factor $k = \sqrt{3}$ and $\nu_i = \infty$.

c) Resolution of Standard Thermometer:

The resolution of the standard thermometer used in the measurement is 0.10 °C and the distribution was considered rectangular. The standard uncertainty (*Ui*) is ±0.029 °C with coverage factor $k = \sqrt{3}$ and $\upsilon_i = \infty$.

d) Heating Conduction Effect of Standard Sensors

The heat conduction effect of standard sensors due to immersion effects. It might be examined from previous knowledge when being immersed at various depths. The standard uncertainty (*Ui*) is ±0.05 °C was considered with rectangular probability distribution with $k = \sqrt{3}$ and $\upsilon_i = \infty$.

e) Self-Heating Effect of Standard Sensors

Where applicable, the RTD standard sensors were calibrated in the different way of use in calibration of the enclosure. The heat transferring effect due to different medial of the sensors might affect the actual temperature. The standard uncertainty (*Ui*) is ±0.05 °C was considered with rectangular probability distribution with $k = \sqrt{3}$ and $\nu\upsilon_i = \infty$.

f) Repeatability in average indicator reading

At 50 °C setting point, the observed values on the display indicator thermometer of chamber measurement remained stable at 50.0 °C. The calculated standard deviation is about 0.0 °C, therefore the standard uncertainty (*Ui*) is ±0.0 °C for n ~20, $k_i = 1$ and ν_i =19).

g) Temperature Stability of Chamber at 50 °C:

The registration is of the temporal variations of air temperature for at least 30 minutes after reaching the steady state of the chamber. The maximum absolute value of the deviation of the registered temperatures is about 2.0 °C. To consider this value as a reflection of instability in the chamber and assume it was due to linear drift. Its effect was assumed rectangular with standard uncertainty (U_i) is ±1.15 °C, $k_i = \sqrt{3}$ and $\nu_i = \infty$.

h) Loading Effect in Chamber

According to the scope of these guidelines, the chamber was calibrated without loading. However the standards and accessories being put inside the chamber during calibration should be considered. It is estimated to be about 20% of the uniformity, therefore, the standard uncertainty (*Ui*) should be approximated of ±0.25 °C, $k_i = \sqrt{3}$ and $\upsilon_i = \infty$.

i) Resolution of Indicator

The resolution or the least significant digit of enclosure indicating device is 0.1 °C. It would affect both measurements and controlled setting, in the sense that it represents the lower limit for uncertainty in their measurement. Apply it once and the uncertainty would be within the range of 0.1 °C. The standard uncertainty (*Ui*) is ±0.029 °C, $k_i = \sqrt{3}$ and $\nu_i = \infty$.

j) Radiation Effect in Chamber

The radiation effect from the chamber walls and all material inside was evaluated. This effect should be investigated by using the proper methods. For the tested air temperature range from 0 °C up to 50 °C, an estimated standard uncertainty of *Ui* = ±0.3 °C, $k_i = \sqrt{3}$ and $\upsilon_i = \infty$ is reasonable without investigation required.

k) The expanded uncertainty in calibration

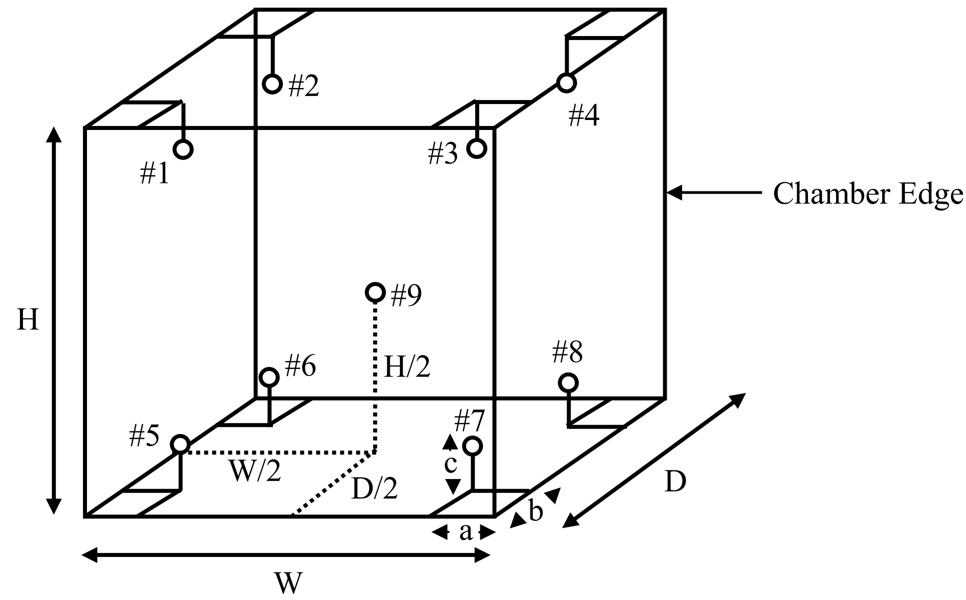
After evaluation of uncertainties contributed above, the calculation of expanded uncertainty shall be performed as follows;

the combined standard uncertainty, u_c = 1.23 °C
the number of effective degrees of freedom, $\nu_{eff} \geq 200$
the coverage factor, k = 2.0
the expanded uncertainty, U = 2.46 °C.
after rounding of expanded uncertainty, U = 2.5 °C.

9. Appendix B: Example of Calibration Report for Temperature Controlled Enclosure Calibration

9.1 Sensor Installation Diagram

For more information, the dimensions of the chamber and the details of sensor installation should be reported.



They may be reported in terms of a three-dimensional region of the chamber and of the associated sensor positions:

- W x H x D = 100 cm x 100 cm x 100 cm
- a x b x c = 5 cm x 5 cm x 5 cm

9.2 Temperature Measurement Accuracy Test

The measurement results of the temperature-controlled enclosure and associates are reported in the manner as shown below.

Model 1: Reporting of correction

Controller Temp. (°C)	Indicating Temp. (°C)	Correction of Temperature (°C) at Spread Locations #1	#2	#3	#4	#5	#6	#7	#8	Ref .9	Uncertainty ±°C
25.0	25.0	0.1	0.3	0.1	0.1	0.1	0.2	0.1	0.1	0.1	2.5
50.0	50.0	0.1	-0.6	0.1	0.1	0.1	-0.5	0.1	0.1	-0.1	2.5
100.0	100.0	0.2	0.5	0.2	0.2	0.3	0.4	0.2	0.2	0.1	2.5
150.0	150.0	0.3	0.5	0.3	0.2	0.3	0.5	0.3	0.2	0.3	2.5

Model 2: Reporting of temperature

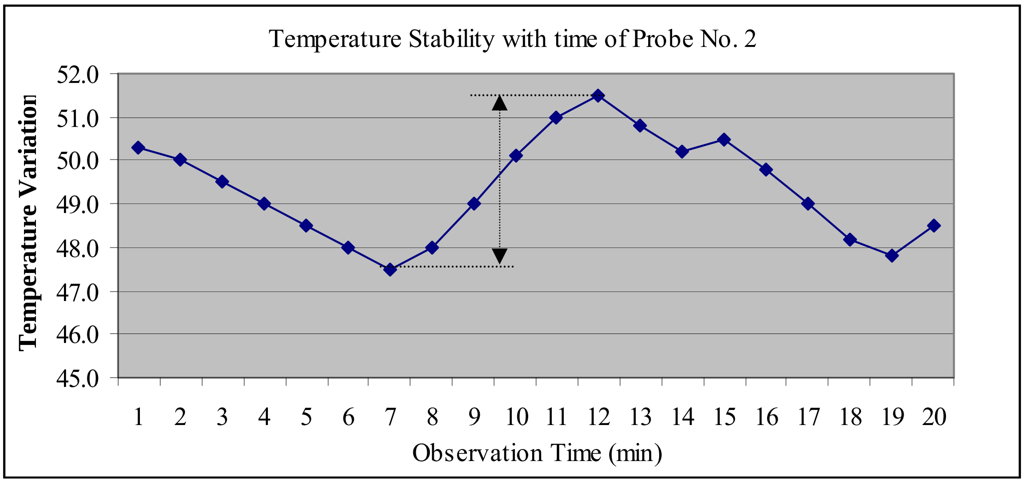
Controller Temp. (°C)	Indicating Temp. (°C)	Measured Temperature (°C) at Spread Locations									Uncertainty ±°C
		#1	#2	#3	#4	#5	#6	#7	#8	Ref .9	
25.0	25.0	25.1	25.3	25.1	25.1	25.1	25.2	25.1	25.1	25.1	2.5
50.0	50.0	50.1	49.4	50.1	50.1	50.1	49.5	50.1	50.1	49.9	2.5
100.0	100.0	100.2	100.5	100.2	100.2	100.3	100.4	100.2	100.2	100.1	2.5
150.0	150.0	150.3	150.5	150.3	150.2	150.3	150.5	150.3	150.2	150.3	2.5

9.3 Chamber Characterization Result

The performance of the enclosure determined in step 4.4 should be reported as shown below:

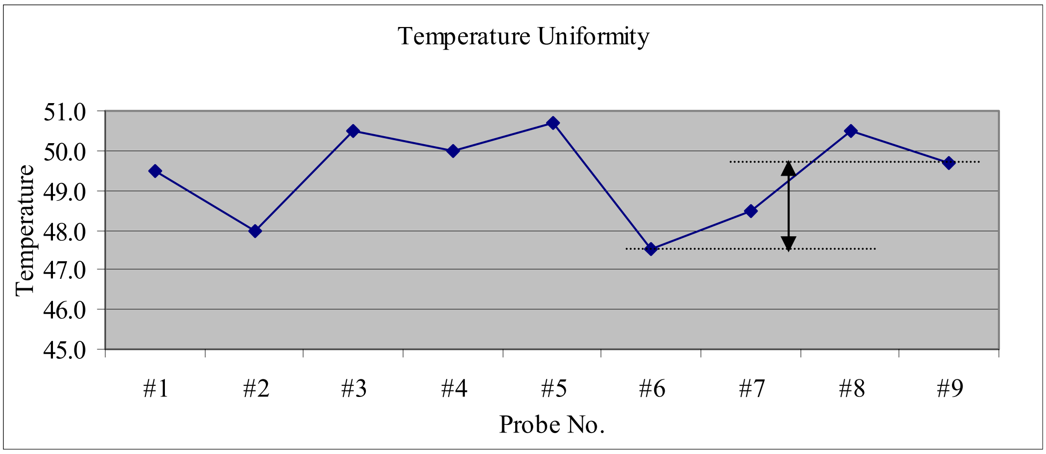
Controller Temperature (°C)	Indicating Temperature (°C)	Temperature Stability (°C)	Temperature Uniformity (°C)	Overall Variation (°C)
25.0	25.0	2.0	2.0	4.1
50.0	50.0	2.0	2.2	4.2
100.0	100.0	2.1	4.0	4.2
150.0	150.0	2.1	4.3	4.3

The temperature stability in graphical report is optional.



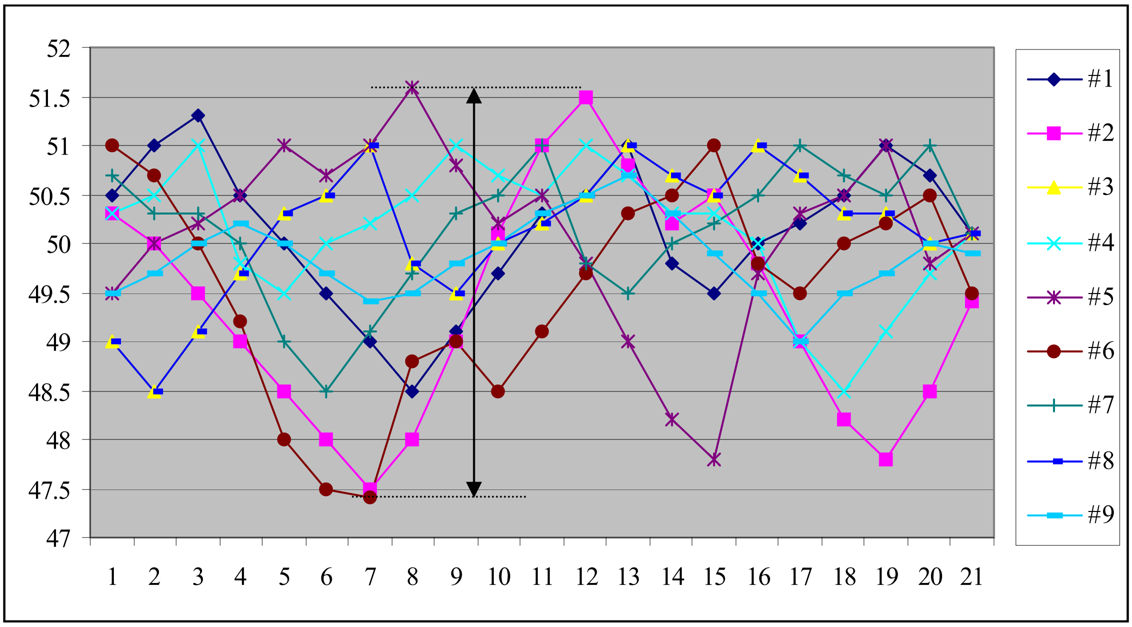
Chamber Stability = ±(51.5-47.5)/2 °C
= ±2.0 °C

The temperature uniformity in graphical report is optional.



Chamber uniformity = (49.7-47.5) °C
= 2.2 °C

The temperature overall variation in graphical report is optional.



Overall Variation = (51.6-47.4) °C
= 4.2 °C

The measured temperature values are mean values from repeated measurements. The chamber temperatures stated were determined using standard thermometers at locations described. The radiation effect due to standard sensor construction and wall emissivity was taken into account in the measurement uncertainty stated. The stated contributions for the characterization of the volume represent the maximum ranges of variation of temperature and humidity, respectively, under the measurement conditions stated. The results stated are valid only for the usage volume of the chamber spanned by the measuring locations. All other parts of the chamber volume are considered not to be calibrated.

The measurement uncertainties for the temperatures were determined from the uncertainties of the standards, of the measurement procedures applied and of the characteristics of the chambers investigated.

The measurement uncertainty stated is the expanded uncertainty which is obtained from the standard uncertainty by multiplication by the expansion factor k=2. With a probability of 95 %, the value of the measurand lies in the interval of values assigned.

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