Infrastructure Commission (INFCOM)

Standing Committee on Measurements, Instrumentation and Traceability (SC-MINT)

Expert Team on Quality, Traceability and Calibration (ET-QTC)

Calibration of humidity instruments

Part-4: Uncertainties

4.2 Uncertainty in relative humidity calibration - Part 2

Written by Drago Groselj (ARSO)

Presented by Stephanie Bell (NPL)

WORLD
METEOROLOGICAL
ORGANIZATION

Calibration of humidity instruments

Overview:

1. Introduction

2. Description of technology

3. Calibration procedures

4. Humidity uncertainties

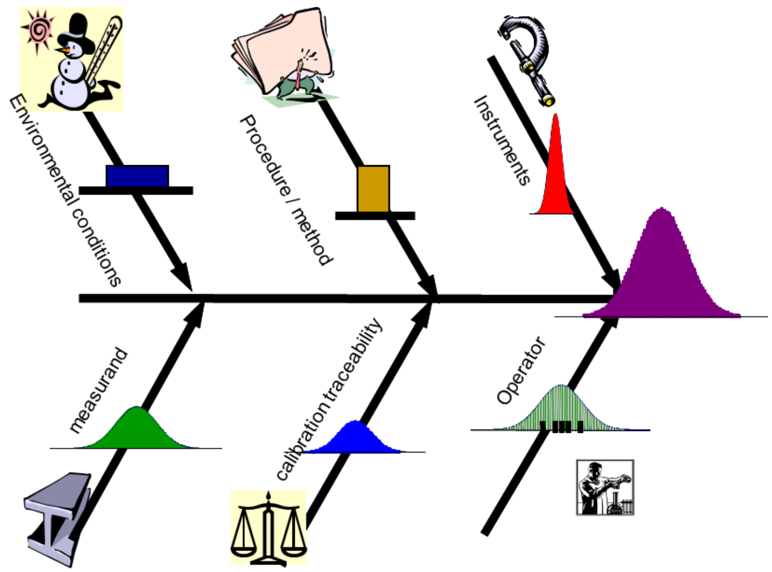
4.1 Uncertainty in relative humidity calibration - Part 1

4.2 Uncertainty in relative humidity calibration - Part 2

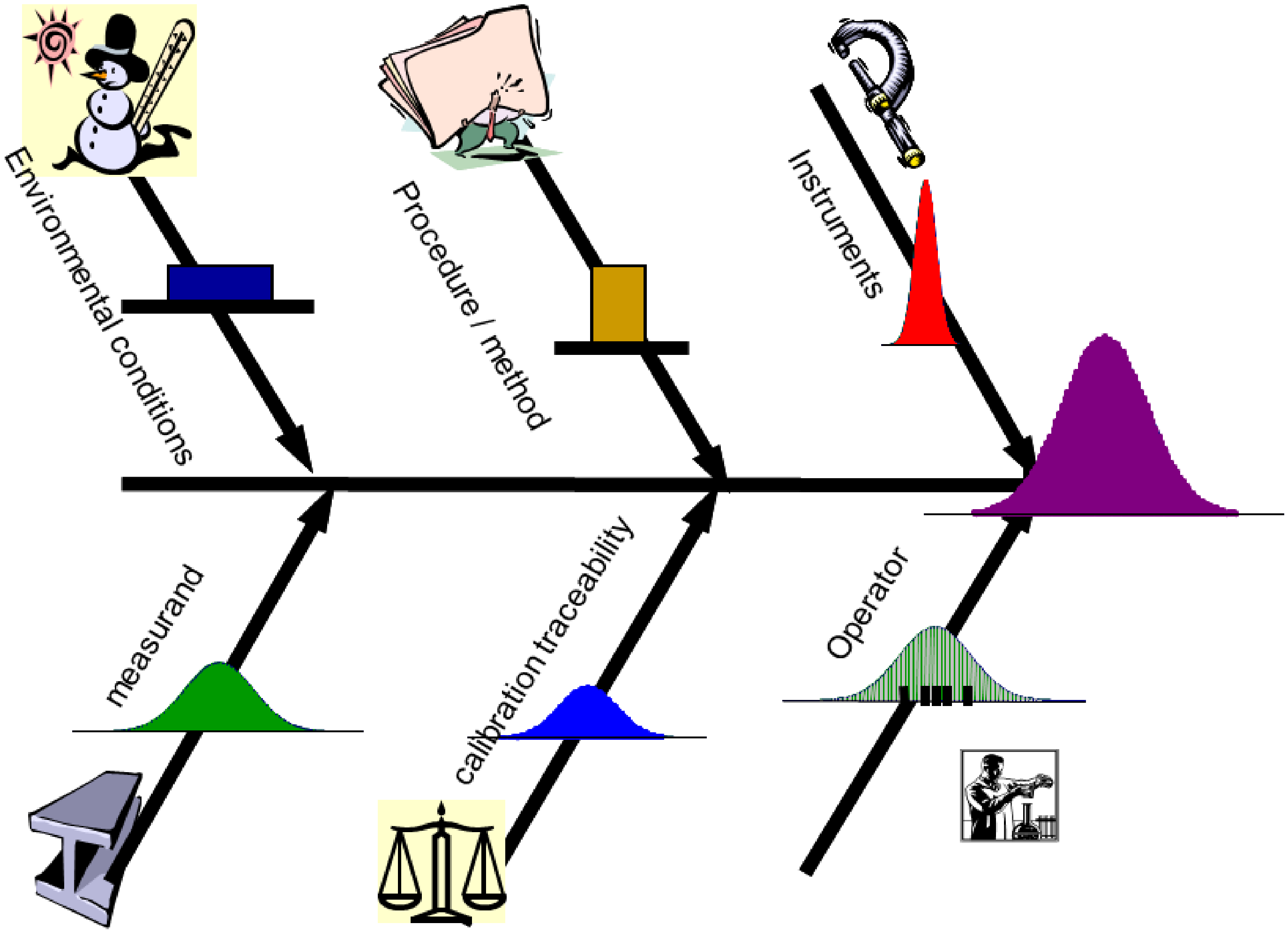
WORLD METEOROLOGICAL ORGANIZATION

Measurement function and uncertainty

$$Y = f\left(X_1, X_2, \ldots, X_N\right)$$



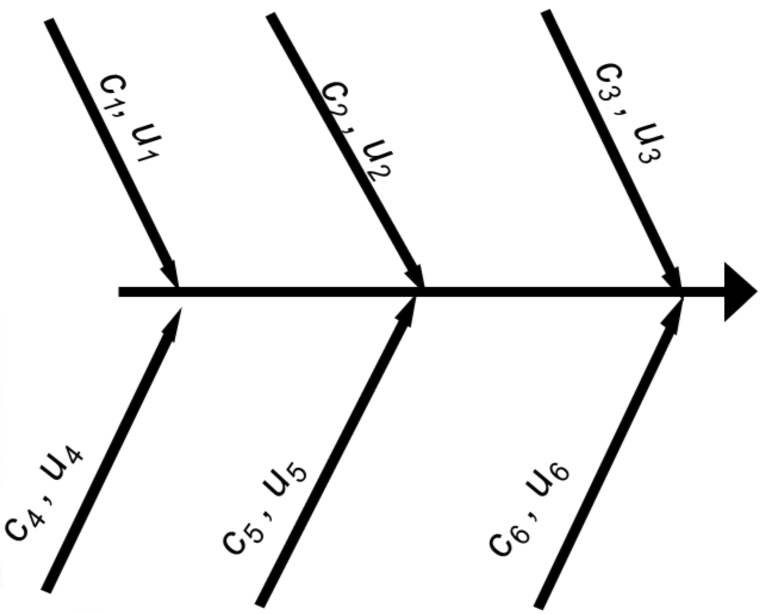
Measurement function and uncertainty

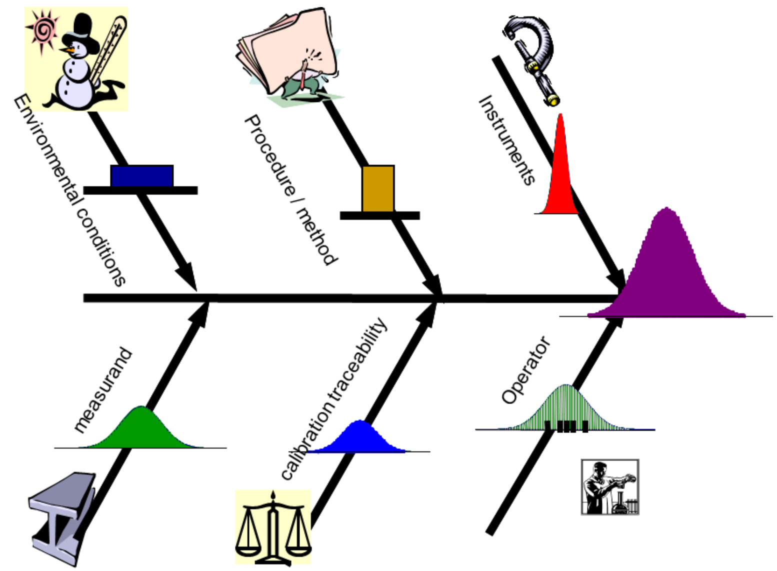


WORLD METEOROLOGICAL ORGANIZATION

Measurement function and uncertainty

$$Y = f\left(X_1, X_2, \ldots, X_N\right)$$





Combined standard uncertainty

$$u\left(y\right) = \sqrt{\sum c_i^2 u_i^2}$$

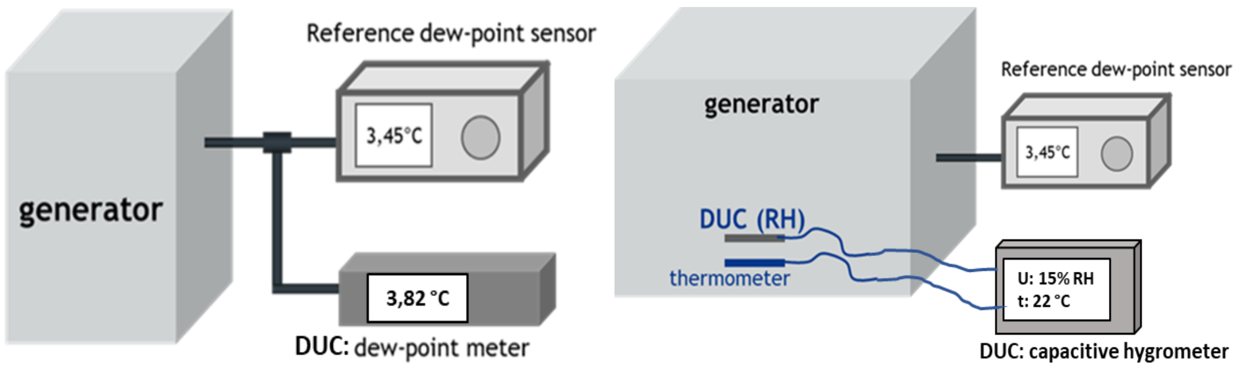
Sensitivity coefficients

$$c_i = \frac{\partial f}{\partial x_i}$$

WORLD METEOROLOGICAL ORGANIZATION

Neglecting correlations between uncertainty components, here

Measurement model and uncertainty - example



Calibration uncertainty budget main aspects:

- due to humidity generation
- due to uncertainty of reference standard
- due to DUC
- due to calibration method and ambient conditions

Example - calibration of capacitive hygrometer by comparison with a reference standard

Equipment used:

- Calibrated reference hygrometer
- Humidity generation: climatic or other humidity chamber, or salt solutions ...

Example measurement cycle:

- 5 readings taken with reference hygrometer
- 5 readings taken with hygrometer to be calibrated
- 5 readings taken with reference hygrometer
- … or more readings, or automated logging ….

Reminder: Salt solution, if used, is only a condition generator - the reference is the hygrometer.

Measurement function

!!! *U = relative humidity*
u = uncertainty

$$Y = f(X_1, X_2, ..., X_N)$$

The correction to be applied the instrument under calibration $= U_{Reference} - U_{Instrument} + [\delta(U)_t + \delta(U)_{stb} + \ldots \delta(U)_{\text{other corrections}}]$

where:	$U_{Reference}$	The reading from the reference hygrometer including potential corrections deriving from its certificate.
	$U_{Instrument}$	The reading from the instrument being calibrated.
	$\delta(U)_x$	Usually, the value of these corrections is taken to be zero on average, but not their uncertainty, which contributes to total uncertainty.

If covariance is negligible, the uncertainty is estimated as: $u_c^2(y) = \sum_{i=1}^{N} \left(\frac{\partial f}{\partial x_i} \right)^2 u^2(x_i)$ *

$$u^2(C) = u^2(U_{Reference}) + u^2(U_{Instrument}) + u^2(\delta(U)t) + ... + u^2(\delta(U)_{\text{other corrections}})$$

WORLD METEOROLOGICAL ORGANIZATION

* Law of propagation of uncertainties, "LPU" – GUM / JCGM:100

Uncertainty budget (example evaluation) - spreadsheet model

Rows and columns ...

Quantity	Brief description	Expanded uncertainty / %RH	Standard uncertainty / %RH	Distribution	Sensitivity coefficient	Uncertainty contribution / %RH
u_{cal}	Calibration uncertainty	1,2	0,6	Normal	1	0,60
u_{drift}	Drift reference hygrometer	0,43	0,25	rectangular	1	0,25
u_{repeat}	repeatability	0,04	0,01	Normal	1	0,01
u_{res}	resolution	0,01	0,003	Rectangular	1	0,00
u_{hyst}	hysteresis	0,1	0,03	Rectangular	1	0,03
u_{Stab}	Generator stability	1	0,3	Rectangular	1	0,29
u_{Hom}	Generator homogeneity	1	0,5	Normal	1	0,50
$u_{repeatDUC}$	DUC repeatability	0,1	0,03	Normal	1	0,03
u_{resDUC}	DUC resolution	0,1	0,03	Rectangular	1	0,03
$u_{combined}$						0,87
Expanded measurement uncertainty U (k=2)						**1,7**

Uncertainty contributions of reference hygrometer (example evaluation)

- **Uncertainty linked to calibration** of reference hygrometer. Calibration expanded uncertainty: 1.2 %RH (k = 2)

$$u_{cal} = 1{,}2/2 = 0{,}6\ \%RH$$

- **Drift** of reference hygrometer is based on the maximal difference between 2 calibrations (0.43 %RH)

$$u_{drift} = 0{,}43/\sqrt{3} = 0{,}25\ \%RH$$

- **Repeatability:** Repeatability can be estimated as variance for a sample set of data (standard deviation of a set of "n" measurements)

$$u_{repea} = s/\sqrt{n} = 0{,}1\ \%RH$$

- **Resolution:** the resolution of the working references is 0.1, the derived uncertainty is:

$$u_{res} = 0{,}1/2\sqrt{3} = 0{,}03\ \%RH$$

- **Hysteresis (if relevant)** the reference calibration reports contain the up (C_{up}) and down (C_{down}) corrections at the same humidity. The hysteresis uncertainty component is expressed from variation ($\delta C = |\ C_{up} - C_{down}\ |$) as follows:

$$u_{hys} = \delta C/2\sqrt{3} = 0{,}1/2\sqrt{3} = 0{,}03\ \%RH$$

Uncertainties linked to the humidity generator (example evaluation)

Stability:

- Previous stability and uniformity study?
- Or after thermal stabilization, the humidity measured with the hygrometers is continuously recorded, typically for longer than 30 min. The humidity variation (standard deviation? worst case?) of the hygrometers over time is used to assign an uncertainty component for stability.

$$u_{stab} = 0{,}3\ \%RH$$

Homogeneity:

- Previous stability and uniformity study?
- Or the hygrometer positions are exchanged one by one and homogeneity uncertainty component is calculated using the indications differences.

$$u_{hom} = 0{,}35\ \%RH$$

Uncertainties linked to device under calibration (DUC) example evaluation

- **Repeatability:** Repeatability can be estimated as variance for a sample set of data (standard deviation of a set of “n” measurements)

$$u_{repeaDUC} = s/\sqrt{n} = 0{,}03\ \%RH$$

- **Data acquisition:** If a multimeter is used for data acquisition for instrument under calibration, so the uncertainty contribution must be accounted for DUC.

$$u_{acquisitionDUC} = 0{,}1\ \%RH$$

- **Resolution:** the resolution of DUC is 0.1, the derived uncertainty is:

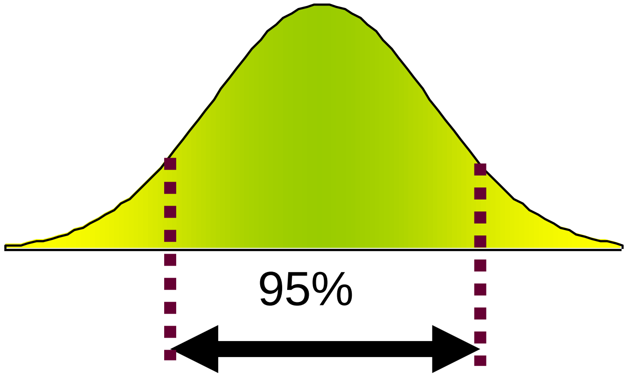
$$u_{resDUC} = 0{,}1/2\sqrt{3} = 0{,}03\ \%RH$$

Combined and expanded uncertainty

Combined uncertainty:

$$u_c = \sqrt{\begin{array}{c} u_{cal}^2 + u_{drift}^2 + u_{temp}^2 + u_{repeat}^2 + u_{res}^2 + u_{hys}^2 \\ + u_{stab}^2 + u_{hom}^2 + u_{repeatDUC}^2 + u_{resDUC}^2 \end{array}}$$

Expanded uncertainty: $U_{\mathrm{expanded}} = k \times u_{\mathrm{c}}$



k = 2, provides a coverage probability of 95 %, assuming an approximately normal distribution

WORLD METEOROLOGICAL ORGANIZATION

Uncertainty budget (example evaluation)

Quantity	Brief description	Expanded uncertainty / %RH	Standard uncertainty / %RH	Distribution	Sensitivity coefficient	Uncertainty contribution / %RH
u_{cal}	Calibration uncertainty	1,2	0,6	Normal	1	0,60
u_{drift}	Drift reference hygrometer	0,43	0,25	rectangular	1	0,25
u_{repeat}	repeatability	0,04	0,01	Normal	1	0,01
u_{res}	resolution	0,01	0,003	Rectangular	1	0,00
u_{hyst}	hysteresis	0,1	0,03	Rectangular	1	0,03
u_{Stab}	Generator stability	1	0,3	Rectangular	1	0,29
u_{Hom}	Generator homogeneity	1	0,5	Normal	1	0,50
$u_{repeatDUC}$	DUC repeatability	0,1	0,03	Normal	1	0,03
u_{resDUC}	DUC resolution	0,1	0,03	Rectangular	1	0,03
$u_{combined}$						0,87
Expanded measurement uncertainty U (k=2)						**1,7**

Cautions:

- This is an outline of an example – your case may differ.
- Quantifying a component of uncertainty sometimes requires judgment – not every aspect has a fixed method for evaluation.
- The drift between past calibrations is informative but is not a predictor of the future; past performance may under-estimate future drift.
- Extra steps are needed if the major components of uncertainty are correlated (not independent)
- Extra steps are needed if the uncertainty is not for a single value but for a more complicated calibration function

Thank you.

wmo.int

WORLD
METEOROLOGICAL
ORGANIZATION