VSL
The Netherlands

BIM - NCM
Bulgaria

Bilateral Comparison of Relative Humidity EURAMET.T-S1

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Author(s): Sasho Nedialkov
Rien Bosma
Erik Dierikx

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1. Introduction

A bilateral comparison has been organized between VSL, the Netherlands and BIM, Bulgaria, in the field of relative humidity measurements. This comparison is registered as EURAMET project 1094 and EURAMET.T-S1 in the BIPM key and supplementary comparison database.

The aim of the comparison is to demonstrate the calibration measurement capabilities (CMC's) of BIM in this working field.

This comparison is organized in the framework of Phare project BG 2005/017-353.02.02, Lot 1, and is in this framework financed by the EU. This project runs from March 2008 to the end of February 2009.

2. Participants and organisation of the comparison

2.1. List of participants

Name:	VSL, Dutch Metrology Institute		
Acronym:	VSL		
Address:	Thijsseweg 11, 2629 JA DELFT		
Country:	The Netherlands		
Contact person:	Rien Bosma	Tel.:	+31 15 269 1663
		E-mail:	rbosma@nmi.nl

Name:	Bulgarian Institute of Metrology – National Centre of Metrology		
Acronym:	BIM - NCM		
Address:	52B blvd.G.M Dimitrov, 1040 Sofia Section “Temperature measurements”		
Country:	Bulgaria		
Contact person:	Sasho Nedialkov	Tel.:	+359 2 76 2946
		E-mail:	s.nedialkov@bim.goverment.bg

Comparison coordinator:
Mr E. Dierikx, VSL Dutch Metrology Institute, The Netherlands
Tel.: +31 15 269 16 88
E-mail: edierikx@nmi.nl

2.2. Comparison schedule

The travelling standard was circulated in a schedule A-B-A, as shown in the table below. The behaviour of the standard during the comparison was determined from the measurements of BIM.

Each participant was allowed approximately 4 weeks to perform the measurements.
The actual schedule is given below.

Participant	Measurements from	to
BIM	01 October 2008	24 October 2008
VSL	20 November 2008	11 December 2008
BIM	02 February 2009	06 March 2009

The travelling standard was hand-carried from one laboratory to the other by experts involved in the Phare project.

3. Travelling standard and measurement instructions

3.1. Description of the standard

The travelling standard is a digital hygrometer, Testo 645, with two measuring probes, type 12s; property of BIM, Bulgaria.

Instrument Model:	Testo 645, sn. 01133442
Measuring probes:	sn. 20142598 sn. 20142601
Size (in packing case):	58 x 51 x 24 cm
Weight (in packing case):	4,5 kg
Owner:	BIM - NCM, Bulgaria
Electrical supply:	230 V / 50 Hz, AC/DC Adapter 9,7 VA
Accessories:	Two measuring cables

3.2. Quantity to be measured and conditions of measurement

The quantity to be measured in this comparison is the deviation of the travelling hygrometer in combination with the two probes, as measured in a sample of moist gas, at predefined levels of temperature and relative humidity as given in Table 1. The moist gas has to be prepared by the participant's standard generator.

Table 1. Measurement points of the comparison

Temperature, °C	Relative humidity, % rh
1	10
1	30
1	60
1	95
50	10

Temperature, °C	Relative humidity, % rh
25	10
25	30
25	60
25	95
50	90

3.3. Measurement instructions

- The participants should refer to the operating manuals for instructions and precautions for using the travelling standards. Participants may perform any initial checks of the operation of the hygrometers that would be performed for a normal calibration. In the case of an unexpected instrument failure at a participant institute, the owner should be informed.

- Sample gas generated by a participant's standard generator, is introduced into travelling standard hygrometer probes.

- Each laboratory should follow its normal practice when calibrating digital hygrometers.

- Each measurement of the pair of probes should be a simultaneous or near-simultaneous measurement of the same applied condition.

- Three repeated, full set of measurements are carried out, i.e. each nominal of relative humidity and temperature should be separately repeated (reproduced) three times to reduce the effect of any irreproducibility of the travelling standards.

- Participants should avoid lengthy additional measurements, except those necessary to give confidence in the results of this comparison.

- The travelling standards used in this comparison must not be modified, adjusted, or used for any purpose other than described in this document, nor given to any party other than the participants in the comparison.

- Participants may apply their own criteria of stability for acceptance of measurements.

3.4. Deviations from the protocol

There have been some deviations from the original schedule. The actual schedule is given in section 2.2 of this document.

4. Methods of measurement

4.1. Method of BIM

4.1.1. Standard equipment

Automatic Relative Humidity Calibration System, including:

- Series 4000 Precision Dew-point Meter – Michell
- Automatic RH Generator – Michell
- Pressure Swing Dryer model PSD2– Michell
- Compressor Station type WA/WD – Durr Technik
- Temperature Test Chamber type T -40/50 – CTS Gmbh

4.1.2. Method of measurement

Travelling standard hygrometer probes and standard dew-point meter probe are situated in temperature test chamber. The automatic RH generator provides gas with nominal flow rate 2 l/min. One part of the generated sample gas (about 0,5 l/min) is introduced into standard dew-point meter probe. The other part of the sample gas is passed into the travelling standard hygrometer probes simultaneously.

Selection of different humidity levels and temperature control is made using PC operating software.
The measurements are made when a good stability of the humidity level and temperature is reached.
Three repeated full set of measurements are carried out for each nominal of relative humidity and temperature to reduce the effect of any irreproducibility of the travelling standards.
For assessment of any drift in the travelling standards during the comparison, BIM laboratory carry out measurements at the beginning and end of the comparison period. The drift will be taken into account in the final analysis of the comparison results.

4.2. Method of VSL

4.2.1. Standard equipment

Calibration setup, including:

- Chilled Mirror Hygrometer – MBW 373Hx
- Humidity Generator – Thunder Scientific Corporation 2500
- Reference thermistors (6x) – Betatherm G2S3KF345G
- Digital Multimeter – Agilent 34420A
- Scanner system – Keithley 7001
- Home built test chamber inserted in test chamber of Humidity Generator

4.2.2. Method of measurement

Both travelling standard hygrometer probes are situated in a home build test chamber. The Humidity Generator flushes this test chamber with a nominal flow rate of 10 l/min. A small part of the generated sample gas (about 0,5 l/min) is directed to Chilled Mirror Hygrometer using its internal pump.

The temperature in the test chamber is measured using the six reference thermistors. These are positioned radial and axial around the chamber for optimal measurement of the gradient inside the test chamber.

The thermistors and hygrometer were measured using a scanner system, a digital multimeter and a Delphi software program.
The measurements are made when a good stability of the humidity level and temperature is reached.

5. Measurement results

The parameter to be compared between the laboratories in this comparison is the difference found between the travelling standards and the laboratory relative humidity standard. The travelling standards are used simply as comparators.

5.1. Results of the participating institutes

The reported results from both laboratories are given below.

Table 2. Results from first and second measurements at BIM-NCM

Nominal value:	First/second meas at BIM	first measurement				second measurement				Mean difference ($\Delta rh_1+\Delta rh_2$)/2
		Applied tempera-ture, °C	Applied relative humidity, rh	measured relative humidity, rh	Difference (applied rh - meas rh) Δrh_1	Applied tempera-ture, °C	Applied relative humidity, rh	measured relative humidity, rh	Difference (applied rh - meas rh) Δrh_2	
10 %RH 1 °C	probe 1 - 20142598	0,97	9,81	11,04	-1.23	1,02	9,69	11,02	-1,33	-1,28
	probe 2 - 20142601	0,97	9,81	10,64	-0,84	1,02	9,69	10,06	-0,37	-0,60
30 %RH 1 °C	probe 1 - 20142598	1,01	30,13	30,81	-0,68	1,03	29,65	30,15	-0,51	-0,59
	probe 2 - 20142601	1,01	30,13	30,42	-0,29	1,03	29,65	29,15	0,49	0,10
60 %RH 1 °C	probe 1 - 20142598	1,01	59,73	60,49	-0,76	1,06	59,77	60,78	-1,01	-0,89
	probe 2 - 20142601	1,01	59,73	60,07	-0,34	1,06	59,77	59,57	0,20	-0,07
95 %RH 1 °C	probe 1 - 20142598	1,07	93,71	95,63	-1,91	1,05	95,41	94,92	0,49	-0,71
	probe 2 - 20142601	1,07	93,71	94,59	-0,88	1,05	95,41	93,76	1,65	0,39
10 %RH 25 °C	probe 1 - 20142598	24,86	10,19	10,50	-0,31	24,98	10,04	10,60	-0,56	-0,43
	probe 2 - 20142601	24,86	10,19	10,36	-0,17	24,98	10,04	10,20	-0,16	-0,16
30 %RH 25 °C	probe 1 - 20142598	24,87	30,04	30,83	-0,79	24,89	29,94	30,34	-0,40	-0,59
	probe 2 - 20142601	24,87	30,04	30,59	-0,55	24,89	29,94	30,13	-0,19	-0,37
60 %RH 25 °C	probe 1 - 20142598	24,86	59,62	61,01	-1,39	24,85	60,20	61,09	-0,89	-1,14
	probe 2 - 20142601	24,86	59,62	60,54	-0,92	24,85	60,20	60,22	-0,02	-0,47
95 %RH 25 °C	probe 1 - 20142598	24,87	93,04	95,11	-2,07	24,79	94,03	95,49	-1,46	-1,76
	probe 2 - 20142601	24,87	93,04	93,49	-0,45	24,79	94,03	94,54	-0,51	-0,48
10 %RH 50 °C	probe 1 - 20142598	50,15	9,89	10,04	-0,15	50,04	9,51	10,59	-1,08	-0,62
	probe 2 - 20142601	50,15	9,89	10,40	-0,51	50,04	9,51	11,30	-1,79	-1,15
90 %RH 50 °C	probe 1 - 20142598	49,92	89,32	89,56	-0,24	50,12	92,54	93,22	-0,68	-0,46
	probe 2 - 20142601	49,92	89,32	90,52	-1,20	50,12	92,54	94,28	-1.74	-1,47

Table 3. Bilateral comparison results

Nominal value	Lab name	Applied temperature – mean value	probe 1 - 20142598			probe 2 - 20142601			Average difference of two probes, Δrh	Standard uncert of applied condition, %rh	Expanded uncert, %rh
			Applied relative humidity*	Measured relative humidity*	Difference*	Applied relative humidity*	Measured relative humidity*	Difference*			
		℃	%rh	%rh	%rh	%rh	%rh	%rh	%rh	%rh	%rh
10 %RH 1 °C	BIM	0,99	9,75	11,03	-1,28	9,75	10,35	-0,60	-0,94	0,40	0,81
	VSL	1,15	10,32	11,43	-1,11	10,35	11,13	-0,78	-0,95	0,05	0,36
30 %RH 1 °C	BIM	1,02	29,89	30,48	-0,59	29,89	29,79	0,10	-0,25	0,66	1,33
	VSL	1,14	28,73	30,00	-1,27	28,70	29,63	-0,93	-1,10	0,11	0,45
60 %RH 1 °C	BIM	1,04	59,75	60,64	-0,89	59,75	59,82	-0,07	-0,48	1,04	2,12
	VSL	1,16	57,47	59,03	-1,56	57,51	59,10	-1,59	-1,58	0,21	0,67
95 %RH 1 °C	BIM	1,06	94,56	95,27	-0,71	94,56	94,18	0,38	-0,16	1,55	3,10
	VSL	1,05	90,65	92,25	-1,60	92,69	95,90	-3,21	-2,41	0,59	2,40
10 %RH 25 °C	BIM	24,92	10,12	10,55	-0,43	10,12	10,28	-0,16	-0,30	0,42	0,85
	VSL	24,93	10,72	10,68	0,04	10,69	10,42	0,27	0,16	0,04	0,24
30 %RH 25 °C	BIM	24,88	29,99	30,59	-0,60	29,99	30,36	-0,37	-0,49	0,60	1,21
	VSL	24,99	29,74	30,18	-0,44	29,72	30,03	-0,31	-0,38	0,09	0,47
60 %RH 25 °C	BIM	24,86	59,91	61,05	-1,14	59,91	60,38	-0,47	-0,81	0,93	1,87
	VSL	25,00	59,25	60,85	-1,60	59,30	60,72	-1,42	-1,51	0,18	0,71
95 %RH 25 °C	BIM	24,83	93,54	95,30	-1,76	93,54	94,02	-0,48	-1,12	1,55	3,10
	VSL	25,03	93,52	95,55	-2,03	93,65	95,62	-1,97	-2,00	0,23	1,18
10 %RH 50 °C	BIM	50,10	9,70	10,32	-0,62	9,70	10,85	-1,15	-0,89	0,38	0,77
	VSL	49,80	10,84	10,76	0,08	10,85	10,59	0,26	0,17	0,04	0,22
90 %RH 50 °C	BIM	50,02	90,93	91,39	-0,46	90,93	92,40	-1,47	-0,96	1,54	3,09
	VSL	49,70	89,84	92,08	-2,24	89,75	91,20	-1,45	-1,85	0,26	1,44

The uncertainty due to the stability of the travelling standards during the period of the measurements is:

$$u_{\mathrm{Stab}} = \frac{\left|\Delta rh_1 - \Delta rh_2\right|}{\sqrt{3}}, \qquad (1)$$

Table 4. Stability of the circulating standard

Nominal value	Probe	Difference (applied rh - meas rh) first measurement Δrh_1	Difference (applied rh - meas rh) second measurement Δrh_2	Stability of transfer standard Δrh_1-Δrh_2	Uncertainty due to the stability U stab
10 %RH 1 °C	1	-1,23	-1,33	0,1	0,06
	2	-0,84	-0,37	-0,47	0,27
30 %RH 1 °C	1	-0,68	-0,51	-0,17	0,10
	2	-0,29	0,49	-0,78	0,45
60 %RH 1 °C	1	-0,76	-1,01	0,25	0,14
	2	-0,34	0,2	-0,54	0,31
95 %RH 1 °C	1	-1,91	0,49	-2,4	1,39
	2	-0,88	1,65	-2,53	1,46
10 %RH 25 °C	1	-0,31	-0,56	0,25	0,14
	2	-0,17	-0,16	-0,01	0,01
30 %RH 25 °C	1	-0,79	-0,4	-0,39	0,23
	2	-0,55	-0,19	-0,36	0,21
60 %RH 25 °C	1	-1,39	-0,89	-0,5	0,29
	2	-0,92	-0,02	-0,9	0,52
95 %RH 25 °C	1	-2,07	-1,46	-0,61	0,35
	2	-0,45	-0,51	0,06	0,03
10 %RH 50 °C	1	-0,15	-1,08	0,93	0,54
	2	-0,51	-1,79	1,28	0,74
90 %RH 50 °C	1	-0,24	-0,68	0,44	0,25
	2	-1,2	-1,74	0,54	0,31

Table 3. Results in calibration point 10 % rh / 1 °C

Nominal value:	Lab name	Average Difference (applied rh - meas rh) Δrh	Expanded uncertainty, % rh
10 %RH / 1 °C	BIM-NCM	-0,94	0,81
	VSL	-0,95	0,36

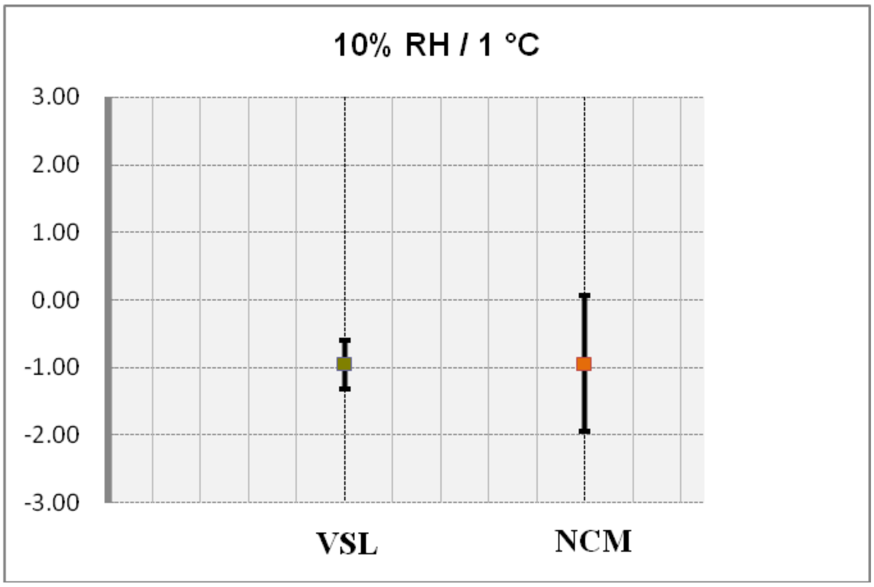


Table 4. Results in calibration point 30 % rh / 1 °C

Nominal value:	Lab name	Average Difference (applied rh - meas rh) Δrh	Expanded uncertainty, % rh
30 %RH / 1 °C	BIM-NCM	-0,25	1,33
	VSL	-1,10	0,45

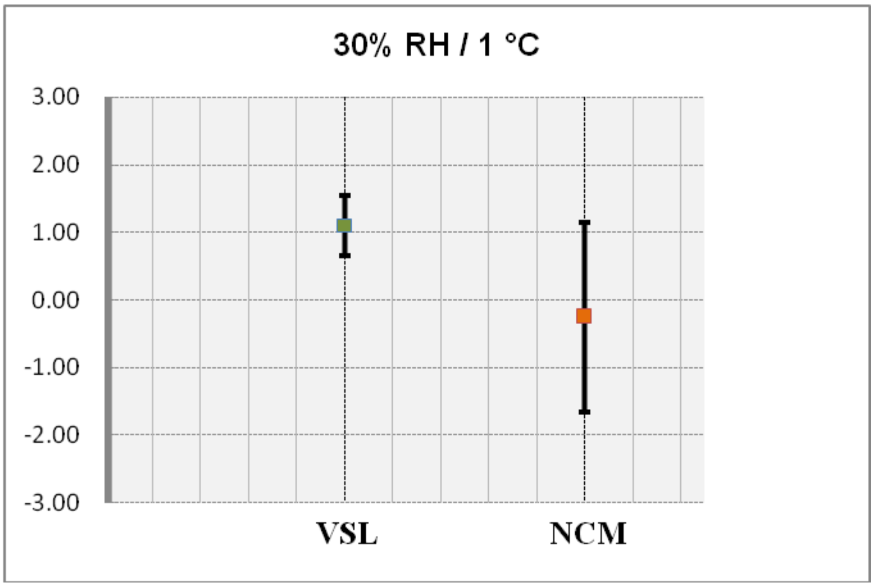


Table 5. Results in calibration point 60 % rh / 1 °C

Nominal value:	Lab name	Average Difference (applied rh - meas rh) Δrh	Expanded uncertainty, % rh
60 %RH / 1 °C	BIM-NCM	-0,48	2,12
	VSL	-1,58	0,67

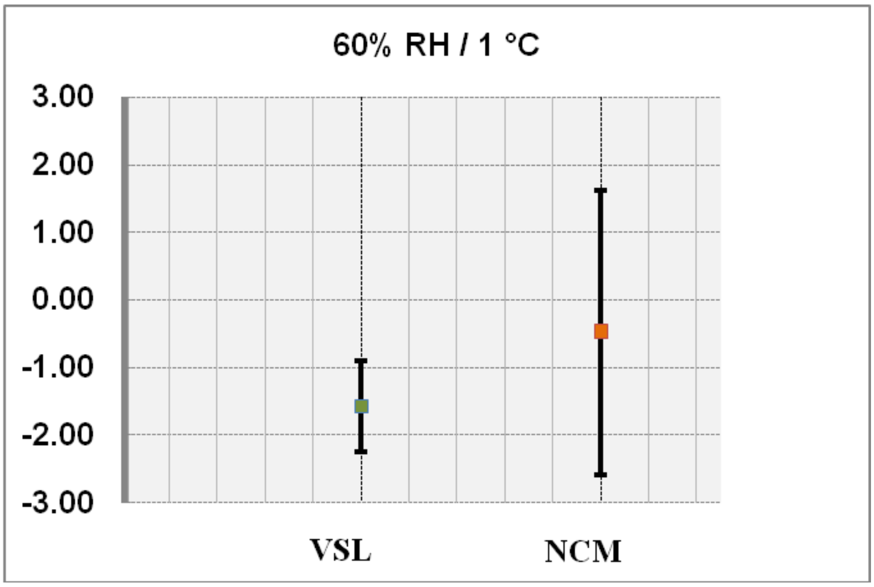


Table 6. Results in calibration point 95 % rh / 1 °C

Nominal value:	Lab name	Average Difference (applied rh - meas rh) Δrh	Expanded uncertainty, % rh
95 %RH / 1 °C	BIM-NCM	-0,16	3,10
	VSL	-2,41	2,40

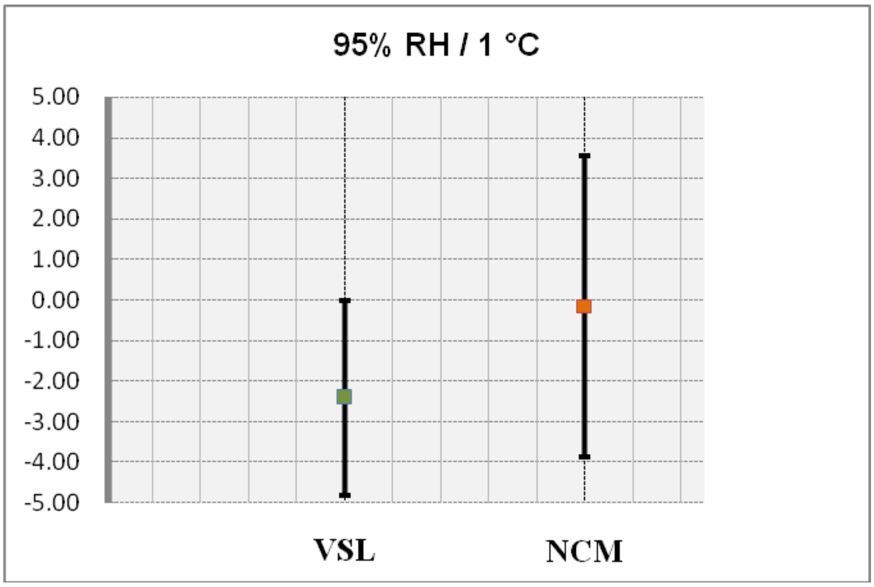


Table 7. Results in calibration point 10 % rh / 25 °C

Nominal value:	Lab name	Average Difference (applied rh - meas rh) Δrh	Expanded uncertainty, % rh
10 %RH 25 °C	BIM-NCM	-0,30	0,85
	VSL	0,16	0,24

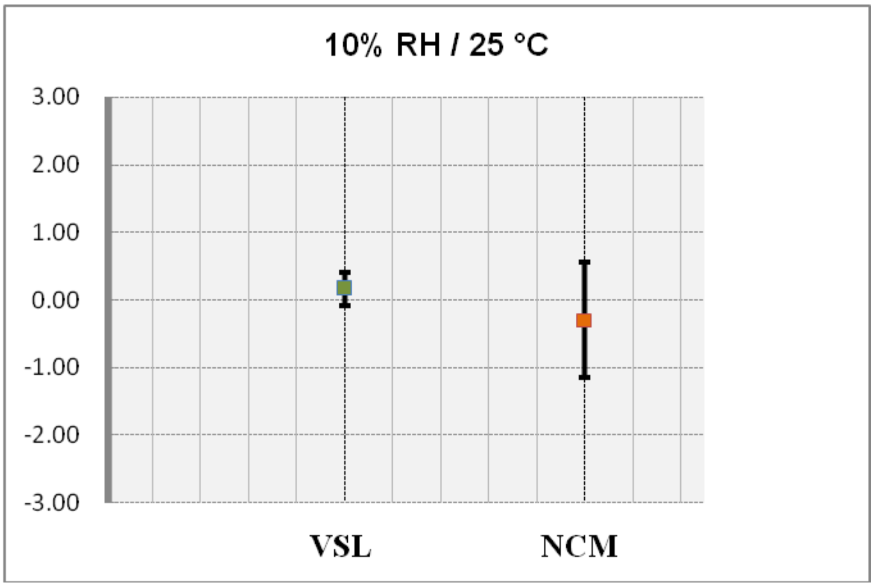


Table 8. Results in calibration point 30 % rh / 25 °C

Nominal value:	Lab name	Average Difference (applied rh - meas rh) Δrh	Expanded uncertainty, % rh
30 %RH 25 °C	BIM-NCM	-0,49	1,21
	VSL	-0,38	0,47

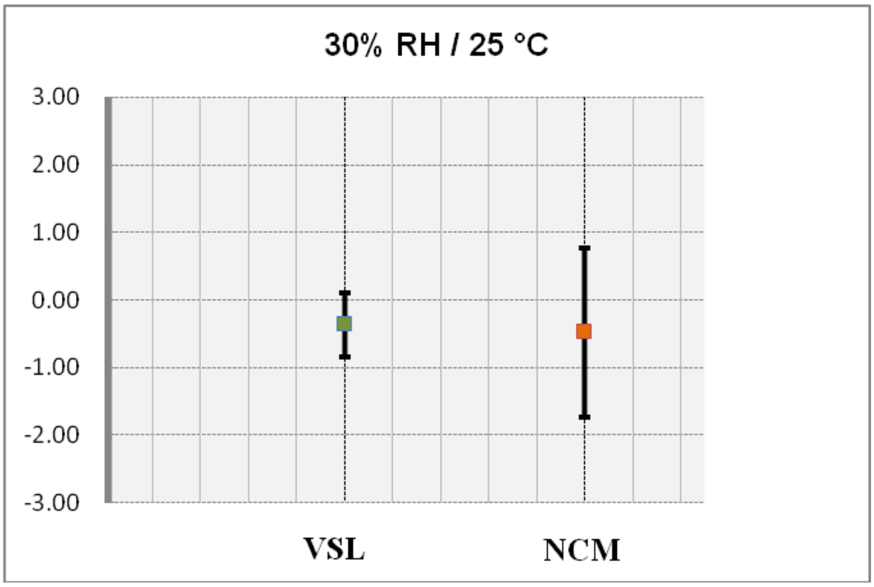


Table 9. Results in calibration point 60 % rh / 25 °C

Nominal value:	Lab name	Average Difference (applied rh - meas rh) Δrh	Expanded uncertainty, % rh
60 %RH 25 °C	BIM-NCM	-0,81	1,87
	VSL	-1,51	0,71

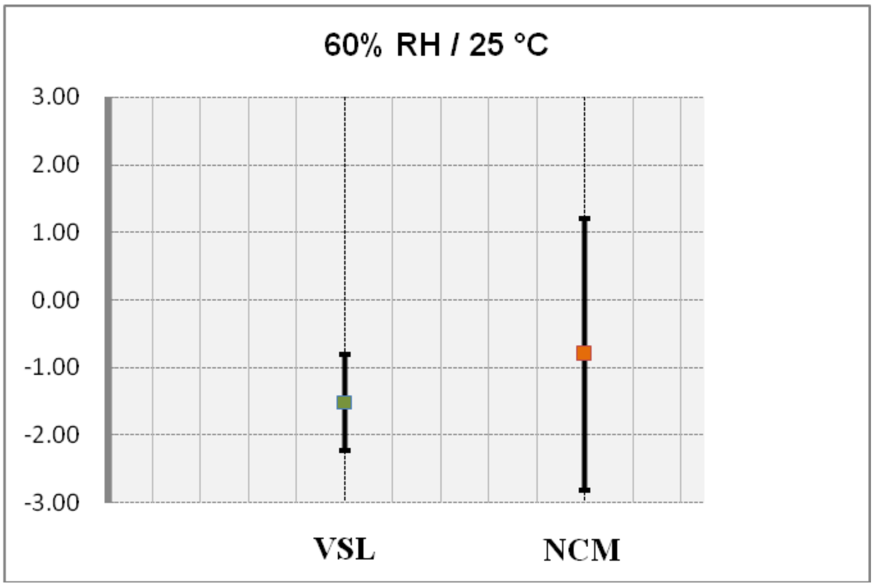


Table 10. Results in calibration point 95 % rh / 25 °C

Nominal value:	Lab name	Average Difference (applied rh - meas rh) Δrh	Expanded uncertainty, % rh
95 %RH 25 °C	BIM-NCM	-1,12	3,10
	VSL	-2,00	1,18

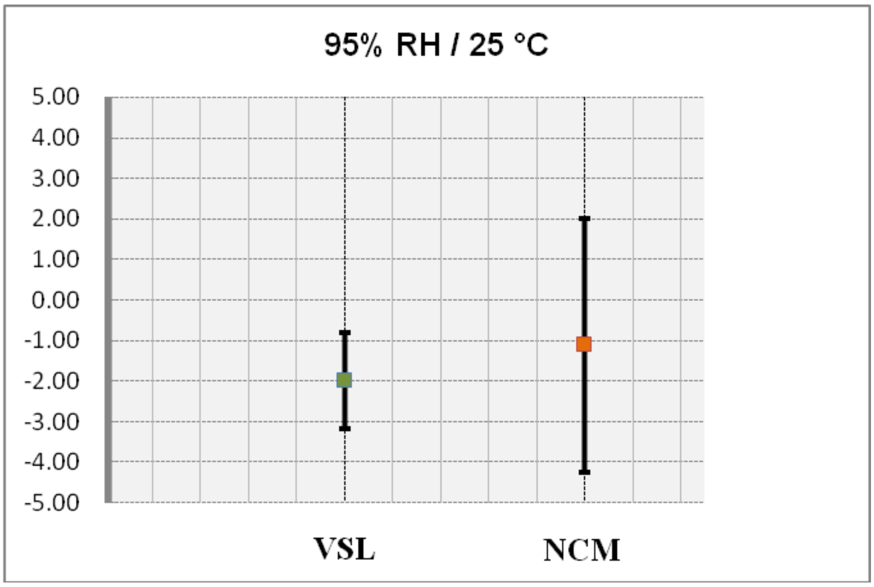


Table 11. Results in calibration point 10 % rh / 50 °C

Nominal value:	Lab name	Average Difference (applied rh - meas rh) Δrh	Expanded uncertainty, % rh
10 %RH 50 °C	BIM-NCM	-0,89	0,77
	VSL	0,17	0,22

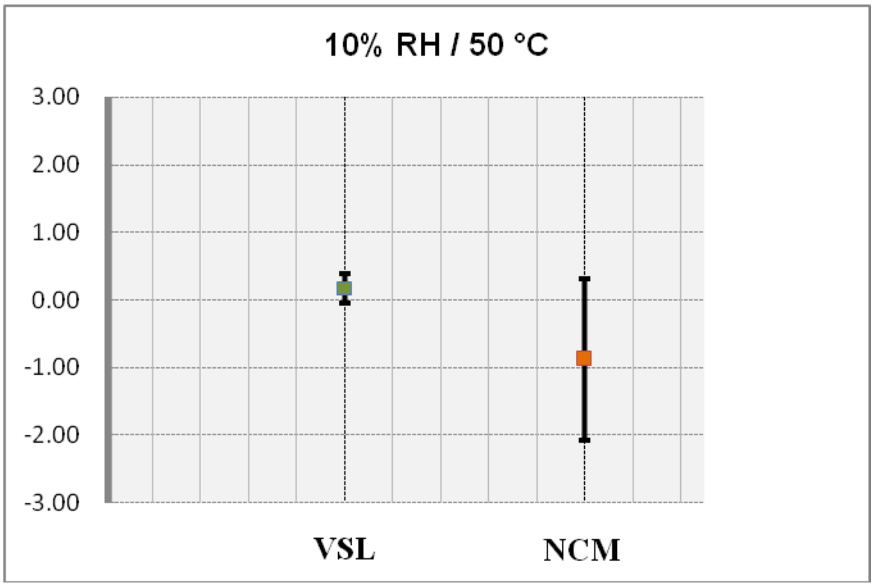
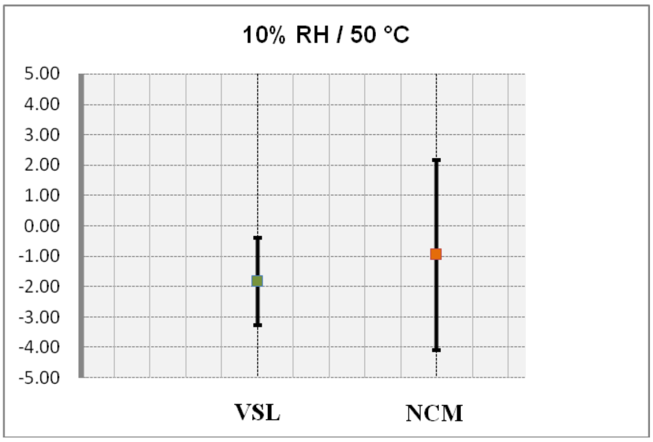


Table 12. Results in calibration point 90 % rh / 50 °C

Nominal value:	Lab name	Average Difference (applied rh - meas rh) Δrh	Expanded uncertainty, % rh
90%RH 50 °C	BIM-NCM	-0,96	3,09
	VSL	-1,85	1,44



5.2. Impact of comparisons on the calibration and measurement capabilities of a participating laboratory (CMCs)

With the results of this comparison, BIM would like to demonstrate its calibration measurement capabilities (CMC's) in the field of measurements of relative humidity. If the results of BIM are in good agreement with the results of VSL, the reported uncertainties of BIM will be the basis of the CMC claims for BIM to be entered in appendix C of the CIPM Mutual Recognition Arrangement (MRA).

5.3. Calibration of the reference value and its uncertainty

5.4. Degrees of equivalence

The degree of equivalence D_{NCM} is given with respect to the measurement results of VSL, which was taken as comparison reference value:

$$D_{NCM} = \Delta rh_{NCM} - \Delta rh_{VSL} \quad (2)$$

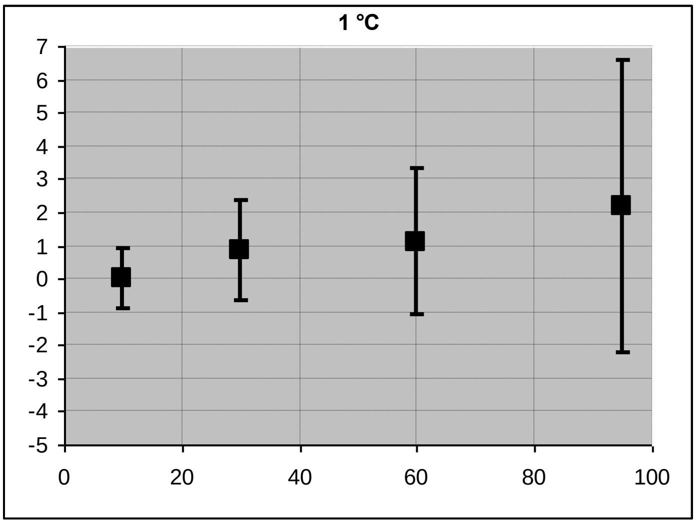
with the expanded uncertainty:

$$U_D = \sqrt{u_{NCM}^2 + u_{VSL}^2 + u_{Stab}^2} \quad (3)$$

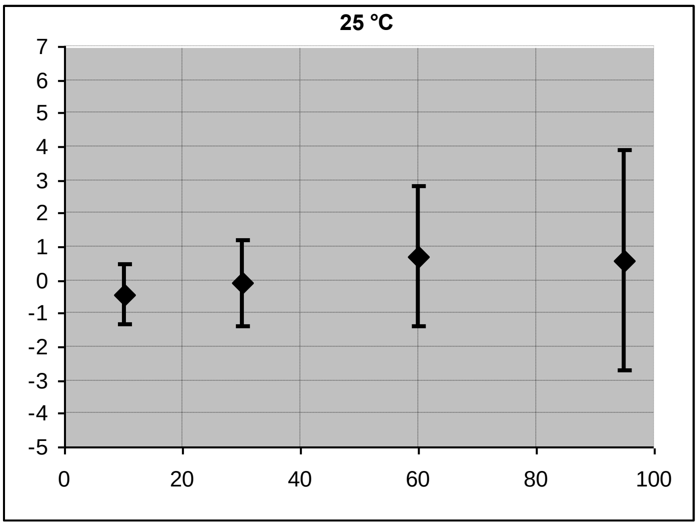
Table 13.

Nominal value:	Degree of equivalence D_{NCM}, % rh	Expanded uncertainty U_D, % rh
10 % rh / 1 °C	0,01	0,93
30 % rh / 1 °C	0,85	1,47
60 % rh / 1 °C	1,1	2,25
95 % rh / 1 °C	2,2	4,18
10 % rh / 25 °C	-0,45	0,89
30 % rh / 25 °C	-0,1	1,32
60 % rh / 25 °C	0,7	2,07
95 % rh / 25 °C	0,6	3,34
10 % rh / 50 °C	1,1	1,09
90 % rh / 50 °C	0,6	3,42

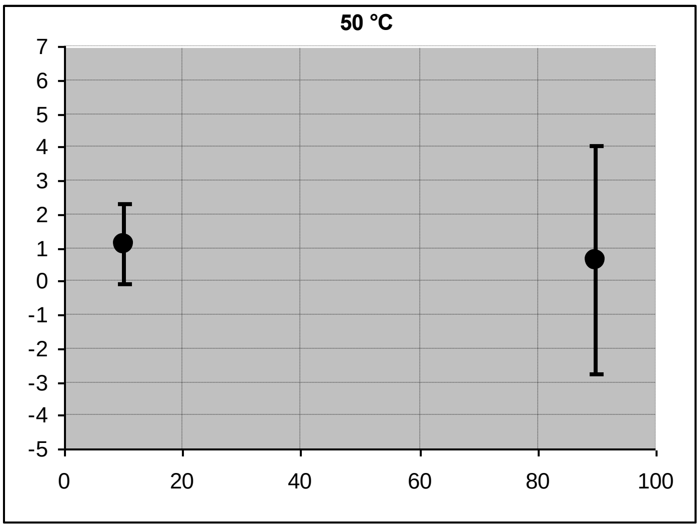
Degree of equivalence at 1°C:



Degree of equivalence at 25 °C:



Degree of equivalence at 50 °C:



6. Summary and conclusions

For the all points of the measurements, there is a good agreement between BIM - NCM and VSL.

Annex A. Uncertainty budgets

A.1 Detailed uncertainty budget of BIM

Nominal value:	10 % rh 1 °C			
Components	probe 1 first meas	probe 2 first meas	probe 1 second meas	probe 2 second meas
Std uncert due to repeatability of measurements of travelling standard (type A)	0,05	0,04	0,05	0,04
Standard uncertainty of applied condition	0,40	0,40	0,40	0,40
Std uncert due to long-term drift of travelling standard	0,07	0,27	0,07	0,27
Std uncert due to resolution of travelling standard	0,03	0,03	0,03	0,03
Combined uncertainty	0,42			
Effective degrees of freedom	1485			
Expanded uncertainty	0,85			

Nominal value:	30 % rh 1 °C			
Components	probe 1 first meas	probe 2 first meas	probe 1 second meas	probe 2 second meas
Std uncert due to repeatability of measurements of travelling standard (type A)	0,15	0,13	0,05	0,04
Standard uncertainty of applied condition	0,66	0,66	0,66	0,66
Std uncert due to long-term drift of travelling standard	0,10	0,45	0,10	0,45
Std uncert due to resolution of travelling standard	0,03	0,03	0,03	0,03
Combined uncertainty	0,70			
Effective degrees of freedom	179			
Expanded uncertainty	1,4			

Nominal value:	60 % rh 1 °C			
Components	probe 1 first meas	probe 2 first meas	probe 1 second meas	probe 2 second meas
Std uncert due to repeatability of measurements of travelling standard (type A)	0,49	0,52	0,32	0,33
Standard uncertainty of applied condition	1,04	1,04	1,04	1,04
Std uncert due to long-term drift of travelling standard	0,14	0,31	0,14	0,31
Std uncert due to resolution of travelling standard	0,03	0,03	0,03	0,03
Combined uncertainty	1,1			
Effective degrees of freedom	81			
Expanded uncertainty	2,1			

Nominal value:	95 % rh 1 °C			
Components	probe 1 first meas	probe 2 first meas	probe 1 second meas	probe 2 second meas
Std uncert due to repeatability of measurements of travelling standard (type A)	0,13	0,31	0,11	0,13
Standard uncertainty of applied condition	1,55	1,55	1,55	1,55
Std uncert due to long-term drift of travelling standard	1,39	1,46	1,39	1,46
Std uncert due to resolution of travelling standard	0,03	0,03	0,03	0,03
Combined uncertainty	1,85			
Effective degrees of freedom	115			
Expanded uncertainty	3,7			

Nominal value:	10 % rh 25 °C			
Components	probe 1 first meas	probe 2 first meas	probe 1 second meas	probe 2 second meas
Std uncert due to repeatibility of measurements of travelling standard (type A)	0,06	0,06	0,18	0,17
Standard uncertainty of applied condition	0,42	0,42	0,42	0,42
Std uncert due to long-term drift of travelling standard	0,09	0,14	0,09	0,14
Std uncert due to resolution of travelling standard	0,03	0,03	0,03	0,03
Combined uncertainty	0,43			
Effective degrees of freedom	368			
Expanded uncertainty	0,86			

Nominal value:	30 % rh 25 °C			
Components	probe 1 first meas	probe 2 first meas	probe 1 second meas	probe 2 second meas
Std uncert due to repeatibility of measurements of travelling standard (type A)	0,03	0,03	0,08	0,04
Standard uncertainty of applied condition	0,60	0,60	0,60	0,60
Std uncert due to long-term drift of travelling standard	0,23	0,21	0,23	0,21
Std uncert due to resolution of travelling standard	0,03	0,03	0,03	0,03
Combined uncertainty	0,62			
Effective degrees of freedom	130			
Expanded uncertainty	1,25			

Nominal value:	60 % rh 25 °C			
Components	probe 1 first meas	probe 2 first meas	probe 1 second meas	probe 2 second meas
Std uncert due to repeatibility of measurements of travelling standard (type A)	0,16	0,17	0,06	0,04
Standard uncertainty of applied condition	0,93	0,93	0,93	0,93
Std uncert due to long-term drift of travelling standard	0,29	0,52	0,29	0,52
Std uncert due to resolution of travelling standard	0,03	0,03	0,03	0,03
Combined uncertainty	0,98			
Effective degrees of freedom	89			
Expanded uncertainty	2,0			

Nominal value:	95 % rh 25 °C			
Components	probe 1 first meas	probe 2 first meas	probe 1 second meas	probe 2 second meas
Std uncert due to repeatibility of measurements of travelling standard (type A)	0,07	0,06	0,10	0,12
Standard uncertainty of applied condition	1,55	1,55	1,55	1,55
Std uncert due to long-term drift of travelling standard	0,35	0,03	0,35	0,03
Std uncert due to resolution of travelling standard	0,03	0,03	0,03	0,03
Combined uncertainty	1,56			
Effective degrees of freedom	58			
Expanded uncertainty	3,1			

Nominal value:	10 % rh 50 °C			
Components	probe 1 first meas	probe 2 first meas	probe 1 second meas	probe 2 second meas
Std uncert due to repeatibility of measurements of travelling standard (type A)	0,01	0,02	0,02	0,04
Standard uncertainty of applied condition	0,38	0,38	0,38	0,38
Std uncert due to long-term drift of travelling standard	0,54	0,74	0,54	0,74
Std uncert due to resolution of travelling standard	0,03	0,03	0,03	0,03
Combined uncertainty	0,60			
Effective degrees of freedom	7587			
Expanded uncertainty	1,2			

Nominal value:	90 % rh 50 °C			
Components	probe 1 first meas	probe 2 first meas	probe 1 second meas	probe 2 second meas
Std uncert due to repeatibility of measurements of travelling standard (type A)	0,16	0,18	0,12	0,12
Standard uncertainty of applied condition	1,54	1,54	1,54	1,54
Std uncert due to long-term drift of travelling standard	0,25	0,31	0,25	0,31
Std uncert due to resolution of travelling standard	0,03	0,03	0,03	0,03
Combined uncertainty	1,56			
Effective degrees of freedom	58			
Expanded uncertainty	3,12			

Uncertainty analysis of RH standard - BIM-NCM

Nominal value:			10 % rh 1 °C	
Components	**Standard uncertainty**	**Degrees of freedom components evaluated by a type A method ***	**Sensitivity coefficient**	**Uncertainty contribution**
	$u_{(Qi)}$	ν_i		u_i **in %rh**
Std uncert due to repeatibility (type A)	0,110	35	1	0,11
Calibration uncertainty (sensor and indicator unit)	0,170	50	1	0,17
Long-term stability (sensor and indicator)	0,290	infinity	1	0,14
Short-term stability (sensor and indicator)	0,170	infinity	1	0,17
Resolution and accuracy or linearity (indicator unit)	0,029	infinity	1	0,03
RH homogeneity	0,058	infinity	1	0,06
Combined standard uncertainty				0,40
Effective degrees of freedom				1198
Expanded uncertainty				0,80

Nominal value:			30 % rh 1 °C	
Components	**Standard uncertainty**	**Degrees of freedom components evaluated by a type A method ***	**Sensitivity coefficient**	**Uncertainty contribution**
	$u_{(Qi)}$	ν_i		u_i **in %rh**
Std uncert due to repeatibility (type A)	0,280	35	1	0,28
Calibration uncertainty (sensor and indicator unit)	0,490	50	1	0,49
Long-term stability (sensor and indicator)	0,290	infinity	1	0,29
Short-term stability (sensor and indicator)	0,170	infinity	1	0,17
Resolution and accuracy or linearity (indicator unit)	0,029	infinity	1	0,03
RH homogeneity	0,058	infinity	1	0,06
Combined standard uncertainty				0,66
Effective degrees of freedom				143
Expanded uncertainty				1,32

Nominal value:			60 % rh 1 °C	
Components	**Standard uncertainty**	**Degrees of freedom components evaluated by a type A method ***	**Sensitivity coefficient**	**Uncertainty contribution**
	$u_{(Qi)}$	ν_i		u_i **in %rh**
Std uncert due to repeatibility (type A)	0,490	35	1	0,49
Calibration uncertainty (sensor and indicator unit)	0,850	50	1	0,85
Long-term stability (sensor and indicator)	0,290	infinity	1	0,29
Short-term stability (sensor and indicator)	0,170	infinity	1	0,17
Resolution and accuracy or linearity (indicator unit)	0,029	infinity	1	0,03
RH homogeneity	0,058	infinity	1	0,06
Combined standard uncertainty				1,04
Effective degrees of freedom				96
Expanded uncertainty				2,08

Nominal value:			95 % rh 1 °C	
Components	**Standard**	**Degrees of freedom**	**Sensitivity**	**Uncertainty**
	uncertainty	**components evaluated**	**coefficient**	**contribution**
		by a type A method *		
	$u_{(Qi)}$	ν_i		u_i **in %rh**
Std uncert due to repeatibility (type A)	0,180	35	1	0,18
Calibration uncertainty (sensor and indicator unit)	1,500	50	1	1,50
Long-term stability (sensor and indicator)	0,290	infinity	1	0,29
Short-term stability (sensor and indicator)	0,170	infinity	1	0,17
Resolution and accuracy or linearity (indicator unit)	0,029	infinity	1	0,03
RH homogeneity	0,058	infinity	1	0,06
Combined standard uncertainty				1,55
Effective degrees of freedom				57
Expanded uncertainty				3,1

Nominal value:			10 % rh 25 °C	
Components	**Standard**	**Degrees of freedom**	**Sensitivity**	**Uncertainty**
	uncertainty	**components evaluated**	**coefficient**	**contribution**
		by a type A method *		
	$u_{(Qi)}$	ν_i		u_i **in %rh**
Std uncert due to repeatibility (type A)	0,170	35	1	0,17
Calibration uncertainty (sensor and indicator unit)	0,170	50	1	0,17
Long-term stability (sensor and indicator)	0,290	infinity	1	0,29
Short-term stability (sensor and indicator)	0,170	infinity	1	0,17
Resolution and accuracy or linearity (indicator unit)	0,029	infinity	1	0,03
RH homogeneity	0,058	infinity	1	0,06
Combined standard uncertainty				0,42
Effective degrees of freedom				755
Expanded uncertainty				0,84

Nominal value:			30 % rh 25 °C	
Components	**Standard**	**Degrees of freedom**	**Sensitivity**	**Uncertainty**
	uncertainty	**components evaluated**	**coefficient**	**contribution**
		by a type A method *		
	$u_{(Qi)}$	ν_i		u_i **in %rh**
Std uncert due to repeatibility (type A)	0,070	35	1	0,07
Calibration uncertainty (sensor and indicator unit)	0,490	50	1	0,49
Long-term stability (sensor and indicator)	0,290	infinity	1	0,29
Short-term stability (sensor and indicator)	0,170	infinity	1	0,17
Resolution and accuracy or linearity (indicator unit)	0,029	infinity	1	0,03
RH homogeneity	0,058	infinity	1	0,06
Combined standard uncertainty				0,60
Effective degrees of freedom				114
Expanded uncertainty				1,2

Nominal value:			60 % rh 25 °C	
Components	**Standard**	**Degrees of freedom**	**Sensitivity**	**Uncertainty**
	uncertainty	**components evaluated**	**coefficient**	**contribution**
		by a type A method *		
	$u_{(Qi)}$	ν_i		u_i **in %rh**
Std uncert due to repeatibility (type A)	0,180	35	1	0,18
Calibration uncertainty (sensor and indicator unit)	0,850	50	1	0,85
Long-term stability (sensor and indicator)	0,290	infinity	1	0,29
Short-term stability (sensor and indicator)	0,170	infinity	1	0,17
Resolution and accuracy or linearity (indicator unit)	0,029	infinity	1	0,03
RH homogeneity	0,058	infinity	1	0,06
Combined standard uncertainty				0,93
Effective degrees of freedom				73
Expanded uncertainty				1,9

Nominal value:			95 % rh 25 °C	
Components	**Standard**	**Degrees of freedom**	**Sensitivity**	**Uncertainty**
	uncertainty	**components evaluated**	**coefficient**	**contribution**
		by a type A method *		
	$u_{(Qi)}$	ν_i		u_i **in %rh**
Std uncert due to repeatibility (type A)	0,180	35	1	0,18
Calibration uncertainty (sensor and indicator unit)	1,500	50	1	1,50
Long-term stability (sensor and indicator)	0,290	infinity	1	0,29
Short-term stability (sensor and indicator)	0,170	infinity	1	0,17
Resolution and accuracy or linearity (indicator unit)	0,029	infinity	1	0,03
RH homogeneity	0,058	infinity	1	0,06
Combined standard uncertainty				1,55
Effective degrees of freedom				57
Expanded uncertainty				3,1

Nominal value:			10 % rh 50 °C	
Components	**Standard**	**Degrees of freedom**	**Sensitivity**	**Uncertainty**
	uncertainty	**components evaluated**	**coefficient**	**contribution**
		by a type A method *		
	$u_{(Qi)}$	ν_i		u_i **in %rh**
Std uncert due to repeatibility (type A)	0,020	35	1	0,02
Calibration uncertainty (sensor and indicator unit)	0,170	50	1	0,17
Long-term stability (sensor and indicator)	0,290	infinity	1	0,29
Short-term stability (sensor and indicator)	0,170	infinity	1	0,17
Resolution and accuracy or linearity (indicator unit)	0,029	infinity	1	0,03
RH homogeneity	0,058	infinity	1	0,06
Combined standard uncertainty				0,38
Effective degrees of freedom				1285
Expanded uncertainty				0,77

Nominal value:				90 % rh 50 °C
Components	**Standard uncertainty**	**Degrees of freedom components evaluated by a type A method ***	**Sensitivity coefficient**	**Uncertainty contribution**
	$u_{(Qi)}$	ν_i		u_i **in %rh**
Std uncert due to repeatibility (type A)	0,140	35	1	0,14
Calibration uncertainty (sensor and indicator unit)	1,500	50	1	1,50
Long-term stability (sensor and indicator)	0,290	infinity	1	0,29
Short-term stability (sensor and indicator)	0,170	infinity	1	0,17
Resolution and accuracy or linearity (indicator unit)	0,029	infinity	1	0,03
RH homogeneity	0,058	infinity	1	0,06
Combined standard uncertainty				1,54
Effective degrees of freedom				56
Expanded uncertainty				3,1

A.2 Detailed uncertainty budget of VSL

Nominal value:	10 % rh 1 °C	
Components	probe 1	probe 2
Std uncert due to repeatibility of measurements of travelling standard (type A)	0,11	0,12
Standard uncertainty of applied condition	0,05	0,05
Std uncert due to long-term drift of travelling standard	0,00	0,00
Std uncert due to resolution of travelling standard	0,03	0,03
Combined uncertainty	0,18	
Effective degrees of freedom	-	
Expanded uncertainty	0,36	

Nominal value:	30 % rh 1 °C	
Components	probe 1	probe 2
Std uncert due to repeatibility of measurements of travelling standard (type A)	0,14	0,06
Standard uncertainty of applied condition	0,11	0,11
Std uncert due to long-term drift of travelling standard	0,00	0,00
Std uncert due to resolution of travelling standard	0,03	0,03
Combined uncertainty	0,23	
Effective degrees of freedom	-	
Expanded uncertainty	0,45	

Nominal value:	60 % rh 1 °C	
Components	probe 1	probe 2
Std uncert due to repeatibility of measurements of travelling standard (type A)	0,14	0,06
Standard uncertainty of applied condition	0,21	0,21
Std uncert due to long-term drift of travelling standard	0,00	0,00
Std uncert due to resolution of travelling standard	0,03	0,03
Combined uncertainty	0,34	
Effective degrees of freedom	-	
Expanded uncertainty	0,67	

Nominal value:	95 % rh 1 °C	
Components	probe 1	probe 2
Std uncert due to repeatibility of measurements of travelling standard (type A)	-	1,00
Standard uncertainty of applied condition	0,59	0,31
Std uncert due to long-term drift of travelling standard	0,00	0,00
Std uncert due to resolution of travelling standard	0,03	0,03
Combined uncertainty	1,20	
Effective degrees of freedom	-	
Expanded uncertainty	2,40	

Nominal value:	10 % rh 25 °C	
Components	probe 1	probe 2
Std uncert due to repeatibility of measurements of travelling standard (type A)	0,02	0,10
Standard uncertainty of applied condition	0,04	0,04
Std uncert due to long-term drift of travelling standard	0,00	0,00
Std uncert due to resolution of travelling standard	0,03	0,03
Combined uncertainty	0,12	
Effective degrees of freedom	-	
Expanded uncertainty	0,24	

Nominal value:	30 %RH 25 °C	
Components	probe 1	probe 2
Std uncert due to repeatibility of measurements of travelling standard (type A)	0,08	0,18
Standard uncertainty of applied condition	0,09	0,09
Std uncert due to long-term drift of travelling standard	0,00	0,00
Std uncert due to resolution of travelling standard	0,03	0,03
Combined uncertainty	0,23	
Effective degrees of freedom	-	
Expanded uncertainty	0,47	

Nominal value:	60 %rh 25 °C	
Components	probe 1	probe 2
Std uncert due to repeatibility of measurements of travelling standard (type A)	0,16	0,20
Standard uncertainty of applied condition	0,18	0,16
Std uncert due to long-term drift of travelling standard	0,00	0,00
Std uncert due to resolution of travelling standard	0,03	0,03
Combined uncertainty	0,36	
Effective degrees of freedom	-	
Expanded uncertainty	0,71	

Nominal value:	95 % rh 25 °C	
Components	probe 1	probe 2
Std uncert due to repeatibility of measurements of travelling standard (type A)	0,39	0,27
Standard uncertainty of applied condition	0,23	0,26
Std uncert due to long-term drift of travelling standard	0,00	0,00
Std uncert due to resolution of travelling standard	0,03	0,03
Combined uncertainty	0,59	
Effective degrees of freedom	-	
Expanded uncertainty	1,18	

Nominal value:	10 % rh 50 °C	
Components	probe 1	probe 2
Std uncert due to repeatibility of measurements of travelling standard (type A)	0,08	0,04
Standard uncertainty of applied condition	0,04	0,04
Std uncert due to long-term drift of travelling standard	0,00	0,00
Std uncert due to resolution of travelling standard	0,03	0,03
Combined uncertainty	0,11	
Effective degrees of freedom	-	
Expanded uncertainty	0,22	

Nominal value:	90 % rh 50 °C	
Components	probe 1	probe 2
Std uncert due to repeatibility of measurements of travelling standard (type A)	0,53	0,32
Standard uncertainty of applied condition	0,26	0,26
Std uncert due to long-term drift of travelling standard	0,00	0,00
Std uncert due to resolution of travelling standard	0,03	0,03
Combined uncertainty	0,72	
Effective degrees of freedom	-	
Expanded uncertainty	1,44	

Annex B. Comparison protocol

Bilateral Comparison of Relative Humidity

1. INTRODUCTION

1.1 This comparison is aimed at establishing the degree of equivalence between relative humidity calibration in the range from 10 % rh to 95 % rh and the ambient temperature range +1 °C to +50 °C among the participating national metrology institutes.

1.2 In the framework of Phare project BG 2005/017-353.02.02, LOT 1, it was decided that a key comparison of relative humidity measurements shall be carried out, between the laboratory of NCM (Bulgaria) acting as organizing laboratory and VSL acting as reference laboratory.

1.3 The procedures outlined in this document cover the technical procedure to be followed during measurement of the travelling standards.

2. ORGANIZATION

2.1 Participants

2.1.1 VSL, Delft, Netherlands, NCM, Sofia, Bulgaria

2.1.2 Reference laboratory - VSL

2.1.3 By their declared intention to participate in this bilateral comparison, the laboratories accept the general instructions and the technical protocol written down in this document and commit themselves to follow strictly the procedures of this protocol.

2.1.4 Once the protocol and list of participants have been approved, no change to the protocol or list of participants may be made without prior agreement of participants.

2.1.5 The participants must be able to submit an uncertainty budget of their humidity standards.

2.2 Method of comparison

2.2.1 The bilateral comparison is a comparison of relative humidity calibration at the participating national institutes.

2.2.2 The comparison will be made by calibration of transfer standard. The laboratory will calibrate 1 digital hygrometer Testo 645 with two measuring probes, property of NCM, Bulgaria. Each measuring probe will independently measure the relative humidity of a sample of moist gas produced by a participant's standard generator using the same measuring process.

2.2.3 Simultaneous measurements using a pair of standards gives information about the within-laboratory consistency of the measurements, the reproducibility of the instrument performance, and continuous feedback about the successful transport of the instruments without any major shift in performance.

2.3 Handling of artefacts

2.3.1 The artefacts should be examined immediately upon receipt at the laboratory. The participants are expected to follow all instructions in the operator's manual provided by the instrument manufacturers for proper unpacking, subsequent packing and shipping to the next participant. During packing and unpacking, the participants should check the contents with the packing list including the operator's manual.

2.3.2. The travelling standards should only be handled by authorized persons and stored in such a way as to prevent damage.

2.3.3. During operation of the travelling standards, if there is any unusual occurrence, the other laboratory should be notified immediately before proceeding.

2.4 Transport of artefacts

2.4.1. The transportation process begins when the artefact leaves the sending laboratory and does not end until it reaches the destination laboratory. All participants should follow the following general guidelines:
(1) Plan the shipment well in advance. The recipient should be aware of any customs issues in their country that would delay the testing schedule. The shipping laboratory must be aware of any national regulations covering the travelling standard to be exported;
(2) Determine the best way to ship the travelling standard to the next participant;
(4) Obtain the recipient's exact shipping address. If possible, have it shipped directly to the laboratory;
(5) Coordinate the shipping schedule with the recipient. The sending laboratory should provide the recipient with the carrier, the exact travel mode, and the estimated time of arrival;
(6) Instruct the recipient to confirm receipt and condition upon arrival to the sender and the pilot.

2.4.2. Each travelling standard is supplied with its shipping container, which is sufficiently robust to ensure safe transportation.

2.5 Timetable

Table 1

Period	Task	Lab.
October 2008	Calibration of transfer standard	NCM
November 2008	Calibration of transfer standard	VSL
December 2008	Calibration of transfer standard	NCM

3. DESCRIPTION OF THE TRAVELLING STANDARDS

3.1. Artefacts

3.1.1. Travelling standard is digital hygrometer Testo 645 with two measuring probes, type 12s property of NCM, Bulgaria.

3.1.2. Details of travelling standards:

Model:	Testo 645
Size (in packing case):	58 x 51 x 24 cm
Weight (in packing case):	4,5 kg
Manufacturer:	Testo GMBH
Owner:	NCM, Bulgaria
Electrical supply:	230 V / 50 Hz, AC/DC Adapter 9,7 VA
Accessories:	Two measuring cables

Approximate value for insurance and customs declaration:
3 500 EUR

Serial numbers of the instruments are:

Testo 645	01133442
Measuring probes:	20142598 20142601

4. MEASUREMENT INSTRUCTIONS

4.1. Measurement process

4.1.1. The participants should refer to the operating manuals for instructions and precautions for using the travelling standards. Participants may perform any initial checks of the operation of the hygrometers that would be performed for a normal calibration. In the case of an unexpected instrument failure at a participant institute, the owner should be informed.

4.1.2. Sample gas generated by a participant's standard generator, is introduced into travelling standard hygrometer probes.

4.1.3. Each laboratory should follow its normal practice when calibrate digital hygrometers.

4.1.4. Each measurement should be conducted with the instruments measuring nominally simultaneously.

4.1.5. Three repeated full set of measurements are carried out, i.e. each nominal of relative humidity and temperature should be separately repeated (reproduced) three times to reduce the effect of any irreproducibility of the travelling standards.

4.1.6. Participants should avoid lengthy additional measurements, except those necessary to give confidence in the results of this comparison.

4.1.7. The travelling standards used in this comparison must not be modified, adjusted, or used for any purpose other than described in this document, nor given to any party other than the participants in the comparison.

4.1.8. NCM laboratory will make an assessment of any drift in the travelling standards during the comparison, based on measurements at the beginning and end of the comparison period. If drift is found, this will be taken into account in the final analysis of the comparison results.

4.1.9. If poor performance or failure of a travelling standard is detected, the owner will propose a course of action, subject to agreement of the participants.

4.2. Data collection

4.2.1. Travelling standard has two probes for relative humidity measurement.

4.2.2. Participants may apply their own criteria of stability for acceptance of measurements.

4.2.3. The data reported for the pair of probes should be for simultaneous or near-simultaneous measurement of the same applied condition.

4.2.4. The measurement points are given in Table 2.

Table 2

Temperature, °C	Relative humidity, % rh		Temperature, °C	Relative humidity, % rh
1	10		25	10
1	30		25	30
1	60		25	60
1	95		25	95
50	10		50	90

5. REPORTING OF MEASUREMENT RESULTS

After NCM has completed its measurements, NCM will send its measurement report to VSL. When VSL has received this measurement report, NCM is no longer allowed to make any changes in its results or in its uncertainties. When VSL has completed its measurements they will also make a measurement report of its results. When all measurements reports have been completed, they will be sent to NCM who will do the data analysis and write the comparison report.

5.1. Participants must report their measurement results of three repeated experiments, within four weeks of completing their measurements.
5.2. The parameter to be compared between the laboratories in this comparison is the difference found between the travelling standards and the laboratory relative humidity standard. The travelling standards are used simply as comparators.

5.3. Participants should report results to the VSL in terms of relative humidity. The main measurement results comprise:

- values of relative humidity applied to the travelling standards, and associated standard uncertainty
- values measured using both travelling standards simultaneously (and their associated uncertainties derived from standard deviation of the set of readings)
- values of difference between applied relative humidity and measured relative humidity.

5.4.From the data measured by each participant, results will be analysed in terms of differences between applied and measured relative humidity. In each case, the difference will be taken between the applied (realised) value and the mean (mid-point) between the two hygrometer values.

5.5. In addition, the difference between the two hygrometer readings on all occasions will be analysed and will serve as a check of consistency.

6. UNCERTAINTY OF MEASUREMENT

6.1. The uncertainty of the bilateral comparison results will be derived from:

- the quoted uncertainty of the relative humidity realisation (applied relative humidity)
- the estimated uncertainty relating to the short-term stability of the travelling standard at the time of measurement
- the estimated uncertainty due to any drift of the travelling standard over the period of the comparison (estimated by the NCM)
- the estimated uncertainty in mean values due to dispersion of repeated results (reflecting the combined reproducibility of laboratory standard and travelling standards)
- the estimated uncertainty die to non-linearity of the travelling standards in any case where measurements are significantly away from the agreed nominal value
- the estimated covariance between applied (laboratory standard) and measured (travelling standard) values of relative humidity (if found significant)
- any other components of uncertainty that are thought to be significant

6.2. Participants are required to submit detailed analyses of uncertainty for their relative humidity standards. Uncertainty analysis should be according to the approach given in the ISO Guide to the Expression of Uncertainty of Measurement. A list of the all significant components of the uncertainty budget should be evaluated, and should support the quoted uncertainties. Type B estimates of uncertainty may be regarded as having infinite degrees of freedom, or an alternative estimate of the number of degrees of freedom may be made following the methods in the ISO Guide. Individual institutes may add to the template any additional uncertainties they consider relevant.

6.3. The pilot laboratory will collect draft uncertainty budgets as background information to the uncertainties quoted by participants for the comparison measurements. The Pilot will review the uncertainty budgets for consistency among participants.
6.4. The uncertainty budget stated by the participating laboratory should be referenced to an internal report and/or a published article.

7. DETERMINATION OF THE BILATERAL COMPARISON REFERENCE VALUE

7.1. The outputs of the bilateral comparison are expected to be:

- Results of individual participants for comparison of the hygrometers against their relative humidity reference in terms of mean values for each hygrometer at each measured value, estimated standard uncertainty of each mean result and estimated standard uncertainty of comparison process (e.g. effect of long-term stability and non-linearity of the travelling standards) if necessary.
- Estimates of bilateral equivalence between the pair of participants at each measured relative humidity.
- A bilateral comparison reference value (BCRV) for each nominal value of relative humidity in the comparison. The BCRV might be calculated as the mean of all valid results of reference laboratory.
- Estimates of equivalence of each participant to the BCRV. This might be expressed in terms of the Degree of Equivalence (DOE) given as a difference and its uncertainty ($\Delta \pm U$), in % rh.

7.2. The NCM lab will make an assessment of any drift in the travelling standards during the comparison. The assessment will be based on initial and final measurements done by the NCM. If drift is found, this will be taken into account in the final analysis of the comparison results. If the drift is small compared with uncertainty values reported by the participants, an estimate for the drift may be set to zero with a standard uncertainty calculated according to the ISO Guide. In a case of a significant drift, the effect is taken into account by assigning a time-dependent value to BCRV, or by other suitable method so that the estimates of equivalence can be meaningfully calculated between results taken at different times.

APPENDIX 1. DETAILS OF PARTICIPATING INSTITUTES

VSL

Contact person:	Rien Bosma
Tel.	+31 15 269 1663
E-mail:	rbosma@nmi.nl
Address:	Thijsseweg 11 2629 JA DELT The Netherlands

NCM

Contact person:	Sasho Nedialkov
Phone:	+395 2 8762946
Fax:	+395 2 9702 735
E-mail:	s.nedialkov@bim.government.bg
Address:	Sofia, blvd. G. M. Dimitrov 52 B Bulgaria

Co-ordinator in the Phare project:
Erik Dierikx

Tel.	+31 15 269 1688
E-mail:	edierikx@nmi.nl