EURAMET.M.FF-S9

Intercomparison of very low air speed standard facilities (0.05-1m/s)

Final Report

Coordinating Institute

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Table of Content

1 Introduction

The comparison is intended to be the first EURAMET intercomparison in air speed with focus on the very low air speeds. Two thermal anemometers circulated amongst the participants in order to calibrate the items at specific velocities within 0.05 m/s to 1 m/s according to their implemented procedure. These instruments are special thermal anemometers for low air speed, mainly used in the application of clean rooms and thermal comfort measurements.

The present report is written according to the guidelines for CIPM key comparison [1] and to the comparison protocol organization for EURAMET TC flow [2].

2 Participants

1	**BEV/E+E** (Austria)	**BEV/E+E Elektronik** Designated Laboratory Langwiesen 7 A-4209 Engerwitzdorf	Dietmar PACHINGER dietmar.pachinger@epluse.at +43 7235 605 275
2	**METAS** (Switzerland)	**Federal Institute of Metrology METAS** Physics and Chemistry / Mechanical Quantities and Ionising Radiation / Flow and Hydrometry Lindenweg 50, CH-3003 Bern-Wabern	Marc DE HUU marc.dehuu@metas.ch Tel. +41 58 387 02 67
3	**PTB** (Germany)	**PTB** Fachbereich Gase 1.4 Bundesallee 100 38116 Braunschweig/Germany	Harald MUELLER harald.mueller@ptb.de +49 531 592 1310
4	**LNE-CETIAT** (France)	**CETIAT** Laboratoire Anémométrie Domaine scientifique de la Doua 54, avenue Niels Bohr 69100 Villeurbanne/France	Isabelle CARE isabelle.care@cetiat.fr +33 4 72 44 49 92
5	**DTI** (Denmark)	**Danish Technological Institute** Installation and Calibration Technology Teknologiparken Kongsvang Allé 29 - DK-8000 Aarhus C – Denmark	John FREDERIKSEN John.Frederiksen@teknologisk.dk +45 7220 1235
6	**INRIM** (Italy)	**INRIM C/o DIASP** PoliTO C. so Duca degli Abruzzi 24 10129 Torino/Italy	Aline PICCATO a.piccato@inrim.it +39 011 0906862
7	**LEI** (Lithuania)	**LEI** Breslaujos Str. 3 – 204/1 LK, LT-44403 Heat equipment research and testing laboratory Kaunas - Lithuania	Agnė BERTAŠIENĖ agne@mail.lei.lt +37037401865

Table 1: list of participants

	2014												2015
	1	2	3	4	5	6	7	8	9	10	11	12	1 - 5
	section 1				section 2			section 3					
Austria (BEV/E+E)	Pilot												
Switzerland (Metas)													
Germany (PTB)													
Austria (BEV/E+E)				Pilot									
France (LNE-CETIAT)													
Denmark (DTI)													
Lithuania (LEI)													
Austria (BEV/E+E)							Pilot						
Italy (INRIM)													
France (LNE-CETIAT)													
Austria (BEV/E+E)													Pilot

Table 2: timetable

3 Description of Transfer Standard

In practice, low air speeds are measured using mainly the measurement principle of thermal heat transfer. A sensor element is heated and the flow around the element transports heat energy from the sensor surface. These types of sensors have their highest sensitivity in the low air speed range limited mainly by natural convection that is generated by the heated sensor itself. For the comparison two different types of thermal anemometers were chosen which differ mainly by their geometry.

Figure 1: thermal anemometer: (left) type SWEMA 03 and (right) type EE75

3.1 Thermal Anemometer Type SWEMA 03

The thermal anemometer Type SWEMA 03 is manufactured by the Swedish Company SWEMA. It is designed for omnidirectional measurements of low air speeds mainly for comfort measurements. To offer good sensor dynamics, a very small NTC Ball is used as a heater element. The holder of the probe has a diameter of 20 mm, the protection tube of 8 mm.

The SWEMA 03 Omnidirectional Flow sensor measures the air speed using small NTC Sensor which is heated to a constant temperature offset. To mount the sensor in a reproducible direction, a red point marks the direction of the incoming flow. The sensor area is very fragile and is protected by a protection tube. Open the screw on the protection tube and fix it on the lowest end, so that the sensor region is fully open. The sensor should not be touched at all. Very small changes may already cause deviations.

3.2 Thermal Anemometer Type EE75

This thermal anemometer is manufactured by the Austrian Company E+E Elektronik and was designed mainly for measurements of laminar flow in clean rooms. The sensor consists of two thin film elements with temperature sensitive resistors. The upper element is heated to a temperature offset due to the temperature measured by the second element. The elements are covered by a head construction to avoid damage but also to homogenize the flow around the element. Due to the construction of the probe and its influence on the wind tunnel flow, it is recommended to insert the probe at least 10 cm into the flow profile. Furthermore it is important to place the sensor accurately in flow direction.

The sensors are mounted on a tube with a Diameter of 12 mm and a length of 0.35 m. Via cable the probe is connected with the transmitter box which calculates the output signal. For the comparison the digital USB output is used. It can be connected with the notebook using the provided USB-Cable. Also provided is a power supply cable which can be connected with the second port on the transmitter.

4 Description of the used calibration method

Each participating lab should calibrate the two transfer standards and evaluate the uncertainty of the calibration results as by their own quality system. The calibration of the transfer standards in the calibration facilities should be performed at the following air speeds:

0.05-0.07 m/s*
0.10 m/s
0.15 m/s
0.20 m/s
0.30 m/s
0.50 m/s
0.70 m/s
1.00 m/s

*0.05-0.07 m/s only with SWEMA 03 probe

Laboratories who cannot reach the full velocity range from 0.05 m/s up to 1.0 m/s will limit their measurements to the velocity range they can realize. Both transfer standards should be fully calibrated

3 times interrupted by a remounting of the probe. They should be considered as two different meters under test and the measurements should be recorded according to the procedure of the respective laboratory. Further, the static pressure in your rig has to be recorded. The data of the probes should not be corrected in any way.

5 The stability determination of the transfer standard

During the comparison, both transfer standards were recalibrated by the pilot laboratory four times in order to check their stability. In the following the measurement results are presented for the SWEMA and the EE75 anemometer in a table and in a diagram. On the x-axis the reference air speed is plotted and on the y-axis measured air speed normalized to the laboratory reference value. This axis assignment applies to all other diagrams.

5.1 Swema

In Figure 2 and Table 3 the calibration results and the corresponding uncertainty are presented. The SWEMA anemometer showed a quite good stability over time. Only for velocities below 0.3 m/s a difference between the measurement results is observed which is however still smaller than the uncertainty of the corresponding velocities. For the calculation of the comparison reference value the median value of the four measurements is used as the contribution of the pilot laboratory.

The median value is defined as the value separating the higher half of a data sample from the lower half. For an even number of data values the median value corresponds to the mean value of the two values separating the upper and lower half. The uncertainty of the median value is calculated as the mean value of the uncertainties of the two data values that are closest to the median value.

The drift of the sensor during the comparison is added as a rectangular distributed uncertainty contribution to the uncertainty of the comparison reverence value.

Stability	January 2014		April 2014		July 2014		Mai 15		MEDIAN	
v [m/s]	x_i	U (k=2)	x_i	U (k=2)	x_i	U (k=2)	x_i	U (k=2)	x_i	U (k=2)
0.05	0.6009	0.3773	0.7557	0.1196	0.8333	0.1429	0.6315	0.3292	0.6936	0.2244
0.1	0.9070	0.1506	0.9038	0.0926	0.9400	0.0648	0.8689	0.0620	0.9054	0.1216
0.15	1.0225	0.0831	1.0088	0.0457	1.0130	0.0383	1.0078	0.0390	1.0109	0.0420
0.2	1.0847	0.0631	1.0542	0.0316	1.0495	0.0306	1.0550	0.0297	1.0546	0.0306
0.3	1.0785	0.0435	1.0614	0.0230	1.0532	0.0263	1.0592	0.0236	1.0603	0.0233
0.5	1.0619	0.0269	1.0641	0.0220	1.0539	0.0211	1.0547	0.0185	1.0583	0.0227
0.7	1.0470	0.0241	1.0443	0.0174	1.0376	0.0115	1.0368	0.0184	1.0409	0.0145
1	1.0328	0.0254	1.0344	0.0154	1.0262	0.0096	1.0255	0.0127	1.0295	0.0175

Table 3: stability determination of the anemometer type SWEMA 03

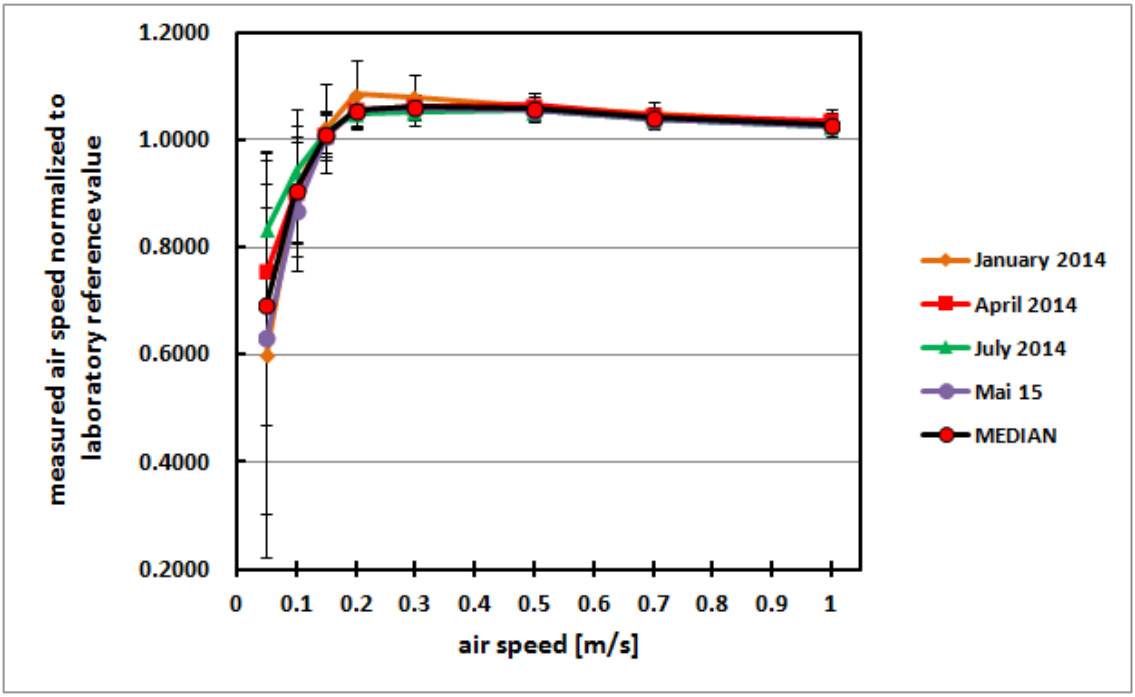

Figure 2: stability determination of the anemometer type SWEMA 03

5.2 EE75

The sensor EE75 suffered from a large instability of up to 10 % during the comparison. This is clearly visible in Figure 3 and Table 4. All measurements that were done before July 2014 and the results of the cleaned sensor can be used for the calculation of the comparison reference value. The other measurements are mentioned for completeness and are thus only included in the test concerning the degree of equivalence.

The reason of the large instability was an oily contamination of the sensor element itself. After cleaning with n-heptane and de-ionized water, the values from July 2014 could be reproduced except a small change of below 0.6 %. An instability of about 2 % is observed over the entire comparison at air speeds higher than 0.4 m/s. This instability is added as a rectangular distributed uncertainty contribution to the uncertainty of the comparison reverence value similar to the drift of the SWEMA.

The median value is calculated of all measurement cycle except the one which was afflicted with the large change due to the contamination. This cycle was accomplished in May 2015 and is marked with a red background in Table 4. Similar to the SWEMA anemometer, the uncertainty of the median value is calculated as the mean value of the uncertainties of the two measurement values that are closest to the median value.

v [m/s]	January 2014		April 2014		July 2014		Mai 2015		Aug 2015		MEDIAN	
	v [rel]	U (k=2)	v [rel]	U (k=2)	v [rel]	U (k=2)	v [rel]	U (k=2)	v [rel]	U (k=2)	v [rel]	U (k=2)
0.1	1.0097	0.0523	0.9936	0.0594	1.0107	0.0607	1.0885	0.0474	1.0057	0.0667	1.0077	0.0595
0.15	1.0439	0.0354	1.0398	0.0337	1.0370	0.0349	1.1376	0.0339	1.0478	0.0145	1.0419	0.0346
0.2	1.0524	0.0261	1.0484	0.0261	1.0431	0.0263	1.1505	0.0254	1.0590	0.0081	1.0504	0.0261
0.3	1.0381	0.0209	1.0350	0.0216	1.0370	0.0223	1.1430	0.0188	1.0402	0.0059	1.0376	0.0216
0.5	1.0066	0.0149	1.0068	0.0149	1.0192	0.0149	1.1107	0.0145	1.0179	0.0047	1.0124	0.0098
0.7	0.9967	0.0130	0.9959	0.0115	1.0136	0.0113	1.0981	0.0127	1.0101	0.0012	1.0034	0.0071
1	1.0123	0.0100	1.0131	0.0101	1.0270	0.0119	1.1133	0.0122	1.0329	0.0027	1.0200	0.0110

Table 4: stability determination of the anemometer type EE75; the red marked values are excluded from the calculation of the median value because of pollution of the sensor; Aug 2015 are the data from the cleaned sensor

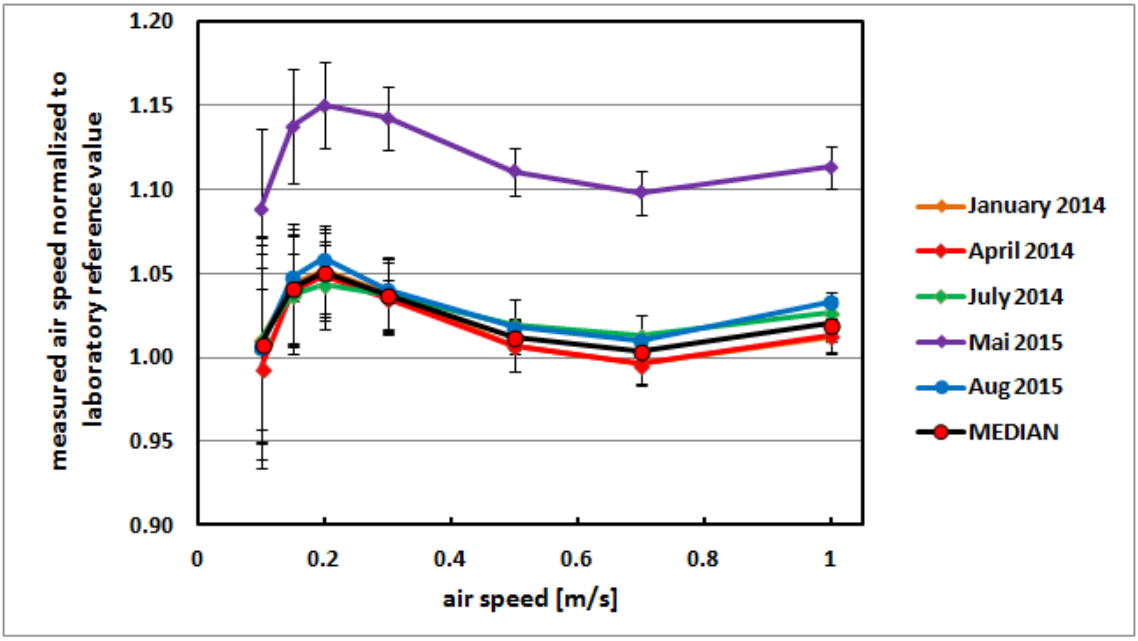

Figure 3: stability determination of the anemometer type EE75

6 The participants results presentation

In this section the laboratory measurement results are presented. The measurement results x_i of each laboratory i (including the pilot laboratory) are presented as the ratio of the averaged air speed measured by the transfer standard to the laboratory reference air speed. Each value x_i represents the mean value of three measurement series.

6.1 SWEMA

Table 5 and Figure 4 show the comparison results of the laboratories based on the SWEMA anemometer and the comparison reference value (CRV). The calculation of the CRV is presented in detail in chapter 7 (equ. 7.1).

Above 0.1 m/s the difference of the measured air speed that is normalized to the laboratory reference value and the comparison reference value (CRV) is smaller than 0.065 for all laboratories. The measurement results from INRIM suffer from a larger deviation from the CRV in the low air speed range.

For 0.1 m/s and 0.05 m/s the difference to the CRV increases to 0.128 and 0.263, respectively. However these data do not fail in the chi-squared test due to large uncertainties. (See chapter 7 - equ. 7.4)

In addition, the calculated comparison reference values (CRV) and the median value of the measurement results of the pilot laboratory are plotted in the Figure 4. For better clarity, uncertainty bars are not shown except for the CRVs. All other uncertainties can be found in Table 5.

lab data	BEV/E+E		METAS		PTB		BEV/E+E		CETIAT hor		CETIAT vert u		DTI	
v [m/s]	x_i	U (k=2)	x_i	U (k=2)	x_i	U (k=2)	x_i	U (k=2)	x_i	U (k=2)	x_i	U (k=2)	x_i	U (k=2)
0.05	0.6009	0.3773	0.7058	0.3433			0.7557	0.1196	0.5269	0.1300	0.7293	0.1634	0.7770	0.4867
0.1	0.9070	0.1506	1.0344	0.6367			0.9038	0.0926	0.8495	0.0666	0.9469	0.0712	0.9846	0.2236
0.15	1.0225	0.0831	1.0133	0.2806			1.0088	0.0457	0.9712	0.0472	1.0236	0.0483	1.0582	0.1533
0.2	1.0847	0.0631	0.9892	0.1531	1.0592	0.0543	1.0542	0.0316	1.0198	0.0371	1.0520	0.0381	1.0807	0.1144
0.3	1.0785	0.0435	0.9948	0.0365	1.0614	0.0422	1.0614	0.0230	1.0337	0.0270	1.0575	0.0277	1.0853	0.0778
0.5	1.0619	0.0269	1.0395	0.0300	1.0536	0.0299	1.0641	0.0220	1.0258	0.0203	1.0449	0.0195	1.0638	0.0509
0.7	1.0470	0.0241	1.0329	0.0361	1.0287	0.0202	1.0443	0.0174	1.0025	0.0161	1.0256	0.0191	1.0405	0.0369
1	1.0328	0.0254	1.0358	0.0306	1.0196	0.0179	1.0344	0.0154	0.9882	0.0152	1.0076	0.0172		

lab data	LEI		BEV/E+E		INRIM T		INRIM R		CETIAT vert d		BEV/E+E		CRV	
v [m/s]	x_i	U (k=2)	x_i	U (k=2)	x_i	U (k=2)	x_i	U (k=2)	x_i	U (k=2)	x_i	U (k=2)	X_{crv}	U (k=2)
0.05	0.8002	0.0875	0.8333	0.1429	1.1217	0.7749			0.5737	0.1624	0.6315	0.3292	0.7899	0.1733
0.1	0.9431	0.0664	0.9400	0.0648	1.1915	0.4450	1.1163	0.3966	0.8888	0.0742	0.8689	0.0620	0.9065	0.0591
0.15	1.0306	0.0538	1.0130	0.0383	1.1678	0.2403	1.1452	0.2316	0.9820	0.0496	1.0078	0.0390	1.0083	0.0276
0.2	1.0669	0.0457	1.0495	0.0306	1.1561	0.1827	1.1435	0.1771	1.0139	0.0382	1.0550	0.0297	1.0500	0.0278
0.3	1.0791	0.0377	1.0532	0.0263	1.1342	0.1506	1.1515	0.1170	1.0287	0.0274	1.0592	0.0236	1.0585	0.0206
0.5	1.0676	0.0284	1.0539	0.0211	1.0943	0.0926	1.0724	0.0687	1.0158	0.0226	1.0547	0.0185	1.0485	0.0123
0.7	1.0463	0.0263	1.0376	0.0115	1.0669	0.0631	1.0417	0.0491	1.0052	0.0214	1.0368	0.0184	1.0389	0.0113
1	1.0336	0.0231	1.0262	0.0096	1.0441	0.0502	0.9984	0.0338	0.9951	0.0172	1.0255	0.0127	1.0259	0.0110

Table 5: SWEMA measurement results of all participants and the calculated CRV

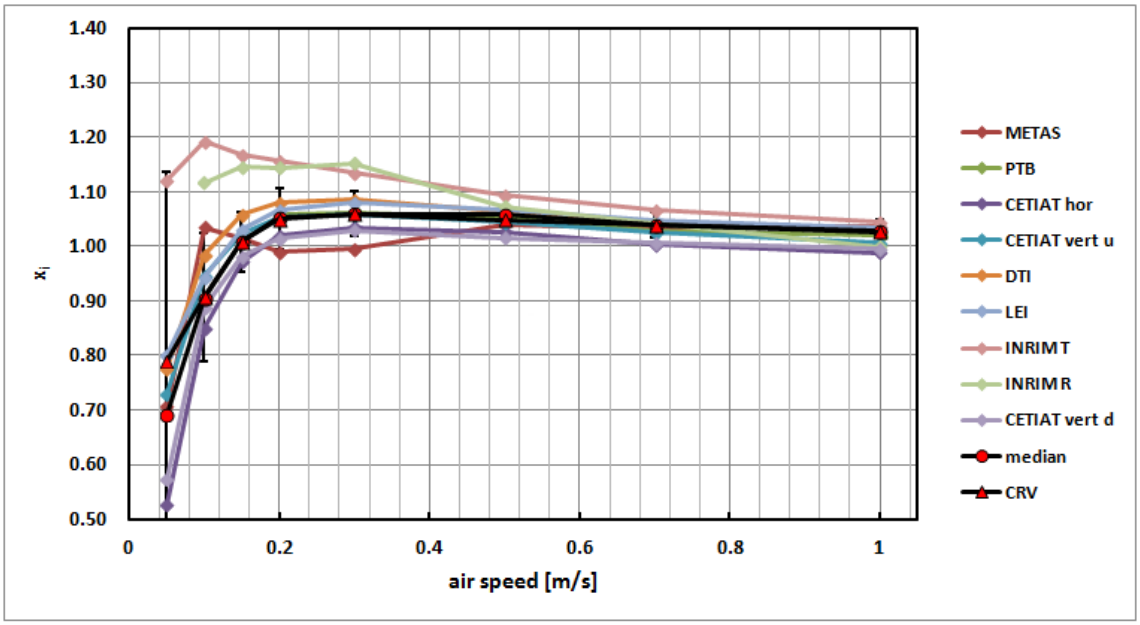

Figure 4: SWEMA measurement results of all participants; including the median values of pilot results and the comparison reference value (CRV)

6.2 EE75

Table 6 and Figure 5 show the laboratory comparison results based on the EE75 anemometer and the calculated CRV. Details concerning the calculation of the CRV can be found in chapter 7 (equ. 7.1). The difference of the comparison results and the CRV is below 0.109 over a large range of air speeds but for low air speeds it is enlarged to 0.148. The outliers of the measurement results at low air speeds do not pass the chi-squared test (see chapter 7 - equ. 7.4) which is obvious when looking at Figure 5. Similar to the SWEMA results, the calculated comparison reverence value (CRV) and the median values of the measurement results of the pilot laboratory are also plotted in Figure 5. Uncertainty bars only for the CRVs are presented, for better clarity.

Lab data	BEV/E+E		METAS		PTB		BEV/E+E		CETIAT hor		CETIAT vert u		DTI	
v [m/s]	x_i	U(k=2)	x_i	U(k=2)	x_i	U(k=2)	x_i	U(k=2)	x_i	U(k=2)	x_i	U(k=2)	x_i	U(k=2)
0.05									1.397	0.090	1.792	0.073		
0.1	1.010	0.026					0.994	0.030	1.100	0.034	1.241	0.038	1.121	0.149
0.15	1.044	0.018	1.017	0.083			1.040	0.017	1.076	0.024	1.124	0.027	1.128	0.088
0.2	1.052	0.013	1.002	0.078	1.094	0.027	1.048	0.013	1.055	0.019	1.091	0.021	1.108	0.061
0.3	1.038	0.010	1.104	0.053	1.057	0.020	1.035	0.011	1.043	0.014	1.055	0.016	1.100	0.038
0.5	1.007	0.007	0.999	0.022	1.023	0.013	1.007	0.007	1.003	0.010	1.007	0.011	1.056	0.023
0.7	0.997	0.007	1.040	0.028	1.011	0.010	0.996	0.006	1.001	0.009	1.006	0.009	1.036	0.017
1	1.012	0.005	1.063	0.013	1.006	0.009	1.013	0.005	1.008	0.008	1.009	0.010		

Lab data	LEI		BEV/E+E		INRIM T		INRIM R		CETIAT hor		CETIAT vert d		BEV/E+E clean		CRV	
v [m/s]	x_i	U(k=2)	x_i	U(k=2)	x_i	U(k=2)	x_i	U(k=2)	x_i	U(k=2)	x_i	U(k=2)	x_i	U(k=2)	X_{crv}	U(k=2)
0.05									1.642	0.075	1.501	0.076				
0.1	1.181	0.032	1.011	0.030	1.249	0.146	1.195	0.164	1.182	0.036	1.066	0.036	1.006	0.067	1.1024	0.1291
0.15	1.142	0.026	1.037	0.017	1.163	0.120	1.114	0.116	1.160	0.024	1.113	0.024	1.048	0.015	1.0545	0.0548
0.2	1.114	0.023	1.043	0.013	1.146	0.089	1.104	0.074	1.145	0.019	1.129	0.019	1.059	0.008	1.0664	0.0372
0.3	1.083	0.024	1.037	0.011	1.116	0.054	1.112	0.052	1.141	0.014	1.142	0.014	1.040	0.006	1.0492	0.0291
0.5	1.026	0.019	1.019	0.007	1.114	0.029	1.057	0.035	1.105	0.016	1.105	0.016	1.018	0.005	1.0132	0.0174
0.7	1.028	0.021	1.014	0.006	1.078	0.020	1.056	0.025	1.106	0.008	1.093	0.008	1.010	0.001	1.0058	0.0158
1	1.033	0.017	1.027	0.006	1.085	0.016	1.061	0.017	1.108	0.008	1.103	0.008	1.033	0.003	1.0148	0.0196

Table 6: EE75 measurement results of all participants and the calculated CRV

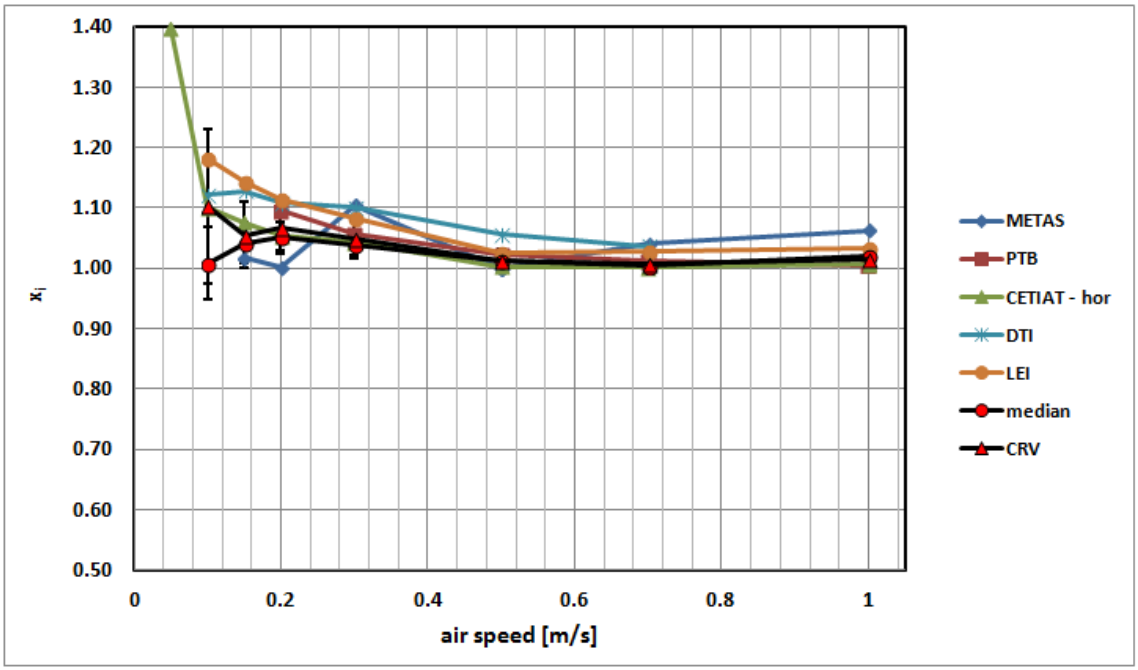

Figure 5: EE75 measurement results of all participants; including the median values of pilot results and the comparison reference value (CRV)

7 The Calculation of the Comparison Reference Value (CRV)

The comparison reference value $x_{i,crv}$ and its corresponding uncertainty are determined according to Cox's report [3,4]. Thereby these values are calculated as weighted means and for each velocity value separately. The determination is carried out according to the procedure A presented by Cox. Additionally, it has to be mentioned that all laboratory values are used for the CRV calculation. Although two laboratories are traced back to PTB, namely BEV/E+E and LEI. The contribution of the laboratories are considered as independent because the contribution of the correlation plays a minor role compared to the installation and calibration procedure.

The comparison reference value is thus given as:

$$x_{i,CRV} = \frac{\frac{x_1}{u_{x1}^2} + \frac{x_2}{u_{x1}^2} + \ldots + \frac{x_n}{u_{xn}^2}}{\frac{1}{u_{x1}^2} + \frac{1}{u_{x2}^2} + \ldots + \frac{1}{u_{xn}^2}} \qquad (7.1)$$

x_1, x_2, …, x_n are the measurement results of the different laboratories

u_{x1}, u_{x2}, …,u_{xn} are standard uncertainties of the laboratories

The standard uncertainty of the comparison reference value $u_{(xi,CRV)}$ is given by

$$\frac{1}{u_{xi,CRV}^2} = \frac{1}{u_1^2} + \frac{1}{u_2^2} + \ldots + \frac{1}{u_n^2} \qquad (7.2)$$

The expanded uncertainty of the comparison reference value is $U_{(xi,CRV)} = 2u$.

The instability of the sensor element over the whole time period is added as a rectangular distributed uncertainty contribution to the whole uncertainty budget. It is calculated according to the formula:

$$u_{drift} = \frac{\left(\max\left(x_{i,January}, x_{i,April}, x_{i,July}, x_{i,Mai/\,August}\right) - \min\left(x_{i,January}, x_{i,April}, x_{i,July}, x_{i,Mai/\,August}\right)\right)}{\sqrt{12}} \qquad (7.3)$$

With x_i is the measured air speed normalized to the laboratory reference value presented in Table 3 and Table 4.

The contributions of both transfer standards are given as follows. The values are normalized to the laboratory reference values at the specific velocity.

v [m/s]	SWEMA	EE75
	$u_{drift,rel}$ (k=1)	$u_{drift,rel}$ (k=1)
0.05	0.0671	-
0.1	0.0205	0.0049
0.15	0.0043	0.0031
0.2	0.0102	0.0046
0.3	0.0073	0.0015
0.5	0.0030	0.0036
0.7	0.0029	0.0051
1	0.0026	0.0059

Table 7: Uncertainty contribution of the drift over time of the comparison

For the calculation of the comparison reverence value the chi-squared test was used to check its consistency. Therefore the chi-squared value X^2_{abs} was calculated by

$$X^2_{abs} = \frac{\left(x_1 - x_{i,CRV}\right)^2}{u^2_{x1}} + \frac{\left(x_2 - x_{i,CRV}\right)^2}{u^2_{x2}} + \ldots + \frac{\left(x_n - x_{i,CRV}\right)^2}{u^2_{xn}} \qquad (7.4)$$

The degree of freedom were assigned as n-1 where n is the number of evaluated laboratories. The consistency check was failing, if $\Pr\left\{X^2_v > X^2_{abs}\right\} < 0.05$. It is calculated with the help of the function $CHIINV(0.05; n)$ provided by MS Excel.

The consistency check passes, if $CHIINV(0.05; n) > X^2_{abs}$. Thus, $x_{i,CRV}$ is accepted as the comparison reference value und $U(x_{i,CRV})$ as the expanded uncertainty of the reference value. However, if the consistency check failed then the laboratory with the highest value of

$$\frac{\left(x_i - x_{i,CRV}\right)^2}{u^2_{xi}} \qquad (7.5)$$

is excluded for the next round of evaluation. Then, again, the reference value, the standard uncertainty of the reference value and the chi-squared value are calculated. This is repeated until the condition for the consistency check is fulfilled. This procedure was applied to both transfer standards and the results are presented in the next section in Table 8 to Table 13.

In addition, it has to be mentioned that CETIAT contributed three measurement series, namely horizontal, vertical up and vertical down, according to their settings of the wind tunnel. For the calculation of the CRV only their main configuration (horizontal) was included. Concerning lab-to-CRV and lab-to-lab comparison, all three configurations are used.

7.1 SWEMA

The results of the chi-squared test for the SWEMA anemometer are presented in the following. The consistency test failed in the first round at four velocities, namely 0.05 m/s, 0.3 m/s, 0.7 m/s and 1 m/s. They are marked with the red color in Table 8. For the second round these values are excluded and the calculation of the chi-squared value is repeated.

Chi²	METAS	PTB	CETIAT horiz	DTI	LEI	INRIM T	INRIM R	BEV/E+E median	sum	n	Chiinv(0.05; n-1)	passed
v [m/s]	chi sqr	chi sqr	chi sqr	chi sqr	chi sqr	chi sqr	chi sqr	chi sqr	chi sqr			
0.05	0.0042		8.5423	0.0610	3.6173	1.0911		0.0433	13.3591	6	11.0705	no
0.1	0.1614		2.9366	0.4873	1.2120	1.6410	1.1193	0.0003	7.5578	7	12.5916	yes
0.15	0.0013		2.4755	0.4242	0.6874	1.7625	1.3961	0.0148	6.7618	7	12.5916	yes
0.2	0.6310	0.1139	2.6577	0.2886	0.5462	1.3475	1.1152	0.0898	6.7900	8	14.0671	yes
0.3	9.1090	0.3043	1.4161	0.8322	2.4095	1.2559	3.0183	0.8083	19.1536	8	14.0671	no
0.5	0.3558	0.1153	4.9773	0.3625	1.8191	0.9813	0.4850	0.7460	9.8422	8	14.0671	yes
0.7	0.0396	0.0041	11.1430	0.3651	1.6603	1.4153	0.2540	2.5571	17.4385	8	14.0671	no
1	1.8564	0.2679	12.3928		2.5923	1.3478	0.9695	2.7375	22.1640	7	12.5916	no

Table 8: SWEMA results of the Chi-squared test, round 1;
the marked red cells do not pass the test;

Chi²	METAS	PTB	CETIAT horiz	DTI	LEI	INRIM T	INRIM R	BEV/E+E median	sum	n	Chiinv(0.05; n-1)	passed
v [m/s]	chi sqr	chi sqr	chi sqr	chi sqr	chi sqr	chi sqr	chi sqr	chi sqr	chi sqr			
0.05	0.2400			0.0028	0.3698	0.7332		0.7367	2.0824	6	11.0705	yes
0.1	0.1614		2.9366	0.4873	1.2120	1.6410	1.1193	0.0003	7.5578	7	12.5916	yes
0.15	0.0013		2.4755	0.4242	0.6874	1.7625	1.3961	0.0148	6.7618	7	12.5916	yes
0.2	0.6310	0.1139	2.6577	0.2886	0.5462	1.3475	1.1152	0.0898	6.7900	8	14.0671	yes
0.3		0.0194	3.3638	0.4742	1.1896	1.0102	2.5238	0.0234	8.6044	7	12.5916	yes
0.5	0.3558	0.1153	4.9773	0.3625	1.8191	0.9813	0.4850	0.7460	9.8422	8	14.0671	yes
0.7	0.1094	1.0244		0.0075	0.3172	0.7867	0.0131	0.0776	2.3359	8	14.0671	yes
1	0.4188	0.4928			0.4380	0.5262	2.6649	0.1651	4.7058	7	12.5916	yes

Table 9: SWEMA results of the chi-squared test, round 2;
the marked red cells are excluded;

From Table 9, it is clearly visible that the chi-squared test is passed for all velocities in the second round. Thus the calculation of the comparison reference value and its uncertainty is possible based on 93.2 % of the original data. The CRV value and the corresponding uncertainty are marked with a green background in Table 10 and as red triangles with a black line in Figure 4.

CRV	METAS		PTB		CETIAT horiz		DTI		LEI		INRIM T		INRIM R		BEV/E+E median		CRV	u_crv
v [m/s]	x_i	U (k=2)	x_i	U (k=2)	x_i	U (k=2)	x_i	U (k=2)	x_i	U (k=2)	x_i	U (k=2)	x_i	U (k=2)	x_i	U (k=2)	Xi	U (k=2)
0.05	0.7058	0.3433					0.7770	0.4867	0.8333	0.0714	1.1217	0.7749			0.6936	0.2244	0.7899	0.1733
0.1	1.0344	0.6367			0.8495	0.0666	0.9846	0.2236	0.9431	0.0664	1.1915	0.4450	1.1163	0.3966	0.9054	0.1216	0.9065	0.0591
0.15	1.0133	0.2806			0.9712	0.0472	1.0582	0.1533	1.0306	0.0538	1.1678	0.2403	1.1452	0.2316	1.0109	0.0420	1.0083	0.0276
0.2	0.9892	0.1531	1.0592	0.0543	1.0198	0.0371	1.0807	0.1144	1.0669	0.0457	1.1561	0.1827	1.1435	0.1771	1.0546	0.0306	1.0500	0.0278
0.3			1.0614	0.0422	1.0337	0.0270	1.0853	0.0778	1.0791	0.0377	1.1342	0.1506	1.1515	0.1170	1.0603	0.0233	1.0585	0.0206
0.5	1.0395	0.0300	1.0536	0.0299	1.0258	0.0203	1.0638	0.0509	1.0676	0.0284	1.0943	0.0926	1.0724	0.0687	1.0583	0.0227	1.0485	0.0123
0.7	1.0329	0.0361	1.0287	0.0202			1.0405	0.0369	1.0463	0.0263	1.0669	0.0631	1.0417	0.0491	1.0409	0.0145	1.0389	0.0113
1	1.0358	0.0306	1.0196	0.0179					1.0336	0.0231	1.0441	0.0502	1.0984	0.0338	1.0295	0.0175	1.0259	0.0110

Table 10: Comparison reference value and its uncertainty for the SWEMA measurement results;
the marked red cells are excluded; green background labels the CRV and its uncertainty;

7.2 EE75

For the EE75 anemometer, the first round of the chi-squared consistency test showed that for three velocities the test is not passed (marked with the red background in Table 11). These are 0.1 m/s, 0.15 m/s and 1 m/s. The calculation for the lowest velocity of 0.05 m/s was not included in the test because data only from one institute are available. The chi-squared test was repeated without the velocities that did not pass the test and the results are presented in Table 12 for the second round.

Chi² v [m/s]	METAS chi sqr	PTB chi sqr	BEV/E+E median chi sqr	CETIAT hor chi sqr	DTI chi sqr	LEI chi sqr	sum chi sqr	n	Chiinv(0.05; n-1)	passed
0.05										
0.1			7.9188	0.0707	0.0401	7.6143	15.6438	4	7.8147	no
0.15	0.4559		3.3621	0.0116	0.3809	7.0673	11.2778	5	9.4877	no
0.2	0.6937	1.0760	1.4990	0.3608	0.4683	4.1453	8.2431	6	11.0705	yes
0.3	1.0581	0.1503	1.1646	0.1934	1.7860	1.9530	6.3054	6	11.0705	yes
0.5	0.4505	0.5572	0.0305	1.0848	3.5173	0.4468	6.0871	6	11.0705	yes
0.7	1.5326	0.3444	0.4610	0.3600	3.2445	1.0858	7.0283	6	11.0705	yes
1	12.2300	2.1852	0.0354	2.2206		0.6659	17.3372	5	9.4877	no

Table 11: EE75 results of the chi-squared test, round 1;
the marked red cells do not pass the test;

v [m/s]	METAS chi sqr	PTB chi sqr	BEV/E+E median chi sqr	CETIAT hor chi sqr	DTI chi sqr	LEI chi sqr	sum chi sqr	n	Chiinv(0.05; n-1)	passed
0.05										
0.1				0.0033	0.0160	0.0160	0.0354	3	5.9915	yes
0.15	0.1999		0.5394	0.8279	0.6931		2.2602	4	7.8147	yes
0.2	0.6937	1.0760	1.4990	0.3608	0.4683	4.1453	8.2431	6	11.0705	yes
0.3	1.0581	0.1503	1.1646	0.1934	1.7860	1.9530	6.3054	6	11.0705	yes
0.5	0.4505	0.5572	0.0305	1.0848	3.5173	0.4468	6.0871	6	11.0705	yes
0.7	1.5326	0.3444	0.4610	0.3600	3.2445	1.0858	7.0283	6	11.0705	yes
1		1.0265	0.9162	0.8649		1.1197	3.9272	4	7.8147	yes

Table 12: EE75 results of the chi-squared test, round 2;
the marked red cells are excluded;

Obviously, all laboratories passed the chi-squared test in the second round and therefore the consistency test is passed with 92.1 % of original data used. According to the above mentioned procedure the comparison reference value and the corresponding uncertainty is calculated. These values are depicted in Table 13 with the green marked cells and in Figure 5 as red triangles with a black line.

CRV	METAS		PTB		BEV/E+E median		CETIAT horiz		DTI		LEI		CRV	uCRVges
v [m/s]	xi	U (k=2)	xi	U (k=2)	xi	U (k=2)	xi	U (k=2)	xi	U (k=2)	xi	U (k=2)	Xi	U (k=2)
0.05							1.3972	0.1791						
0.1							1.1004	0.0676	1.1212	0.2974	1.1212	0.1487	1.1024	0.1291
0.15	1.0173	0.1666			1.0419	0.0346	1.0761	0.0474	1.1280	0.1765			1.0545	0.0548
0.2	1.0016	0.1556	1.0945	0.0135	1.0504	0.0261	1.0551	0.0378	1.1079	0.1212	1.1142	0.0470	1.0664	0.0372
0.3	1.1040	0.1065	1.0568	0.0098	1.0376	0.0216	1.0431	0.0277	1.1002	0.0763	1.0832	0.0486	1.0492	0.0291
0.5	0.9986	0.0435	1.0233	0.0067	1.0124	0.0098	1.0030	0.0197	1.0560	0.0456	1.0262	0.0388	1.0132	0.0174
0.7	1.0403	0.0558	1.0114	0.0048	1.0034	0.0071	1.0007	0.0170	1.0364	0.0340	1.0278	0.0423	1.0058	0.0158
1			1.0056	0.0045	1.0200	0.0110	1.0078	0.0151			1.0333	0.0349	1.0148	0.0196

Table 13: Comparison reference value and its uncertainty for the EE75 measurement results;
the marked red cells are excluded; green background labels the CRV and its uncertainty;

8 Degree of Equivalence with the reference value

With a passed consistency check and with the calculated comparison reference value it is possible to determine the degree of equivalence d_i between each laboratory value x_i and the reference value $x_{i,CRV}$. The formulas for the degree of equivalence and the expanded uncertainty are as follows:

$$d_i = x_i - x_{i,CRV} \qquad (8.1)$$

$U(d_i) = 2 * \sqrt{u_{xi}^2 - u_{xi,crv}^2}$ for independent laboratories contributing to the CRV (8.2)

$U(d_i) = 2 * \sqrt{u_{xi}^2 + u_{xi,crv}^2}$ for independent laboratories not contributing to the CRV (8.3)

The calculation results are indicated in Table 14 for the SWEMA anemometer and in Table 15 for the EE75 anemometer. The $|E_i|$ criterion for a sufficient degree of equivalence is defined as follows:

$$E_i = \frac{d_i}{U(d_i)} \qquad (8.4)$$

The criterion is fulfilled, if $|E_i| \leq 1$. It fails, if $|E_i| > 1$. This is marked with the red color in both tables.

Furthermore, it is possible to determine the degree of equivalence between the different laboratories. This is done with the following formulas:

$$d_{i,j} = x_i - x_j \qquad (8.5)$$

$$U(d_{ij}) = 2 * u(d_{ij}) \qquad (8.6)$$

$$u^2(d_{ij}) = u^2(x_i) + u^2(x_i) \qquad (8.7)$$

A criterion for the matching of the laboratory values is the coefficient $E_{i,j.}$ A laboratory passes if $|E_{i,j}| \leq 1$ and fails if $|E_{i,j}| > 1$.

$$E_{i,j} = \frac{d_{i,j}}{U(d_{i,j})} \qquad (8.8)$$

The results for this lab-to-lab comparison are presented in section 9. Again, the values that do not meet the criterion are labeled with the red color. (Table 16: SWEMA, Table 17: EE75)

8.1 SWEMA

The degree of equivalence of the comparison of the laboratory values to the CRV show that a very good match is achieved for the majority of laboratories. A summary of the determined E_n-values (equ. 8.4) for

each laboratory and the corresponding velocity can be found in Table 14 and in Figure 6. Obviously, the data of CETIAT match quite well to the CRV for the vertical up configuration. Only the data for 1 m/s for the vertical up configuration do not fulfill the $|E_i|$ criterion. Regarding the other configurations, the data for the velocities of 0.05 m/s, 0.5 m/s, 0.7 m/s, 1 m/s for the horizontal configuration and the velocities of 0.5 m/s, 0.7 m/s and 1 m/s for the vertical down configuration do not fulfill the $|E_i|$ criterion.

METAS does not fulfill this criterion only for the velocity of 0.3 m/s.

All other institutes fulfill the criterion for all velocities mentioned. Thus a very good accordance for the calculated comparison reference value is achieved.

Degree of equivalence										
v [m/s]	BEV/E+E (median)		METAS		PTB		CETIAT horzontal		CETIAT vertical up	
	d_i	U(k=2)	d_i	U(k=2)	d_i	U(k=2)	d_i	U(k=2)	d_i	U(k=2)
0.05	0.1178	0.4618	0.1056	0.3603			0.2845	0.2025	0.0821	0.1966
0.1	0.0011	0.2430	0.1279	0.6366			0.0570	0.0657	0.0404	0.0704
0.15	0.0026	0.0803	0.0050	0.2795			0.0372	0.0402	0.0153	0.0415
0.2	0.0046	0.0617	0.0608	0.1533	0.0092	0.1435	0.0302	0.0378	0.0020	0.0389
0.3	0.0018	0.0467	0.0637	0.0419	0.0029	0.0571	0.0248	0.0271	0.0010	0.0278
0.5	0.0098	0.0445	0.0090	0.0286	0.0051	0.0291	0.0227	0.0182	0.0036	0.0172
0.7	0.0020	0.0279	0.0060	0.0353	0.0102	0.0270	0.0364	0.0196	0.0133	0.0175
1	0.0036	0.0341	0.0099	0.0294	0.0063	0.0210	0.0377	0.0188	0.0183	0.0150

v [m/s]	DTI		LEI		INRIM T		INRIM R		CETIAT vert d	
	di	U(k=2)	d_i	U(k=2)	d_i	U(k=2)	d_i	U(k=2)	d_i	U(k=2)
0.05	0.03437	0.498854	0.0113	0.1400	0.3103	0.7826			0.2377	0.1957
0.1	0.07806	0.223378	0.0365	0.0655	0.2850	0.4449	0.2098	0.4165	0.0177	0.0734
0.15	0.04991	0.151233	0.0223	0.0477	0.1595	0.2390	0.1368	0.2338	0.0263	0.0430
0.2	0.03072	0.114612	0.0169	0.0463	0.1061	0.1829	0.0935	0.1763	0.0361	0.0389
0.3	0.0268	0.077858	0.0206	0.0378	0.0757	0.1506	0.0930	0.1179	0.0298	0.0275
0.5	0.01532	0.050078	0.0191	0.0269	0.0459	0.0921	0.0239	0.0694	0.0327	0.0207
0.7	0.0016	0.036134	0.0074	0.0252	0.0280	0.0626	0.0028	0.0485	0.0337	0.0200
1			0.0076	0.0215	0.0182	0.0495	0.0276	0.0329	0.0308	0.0151

Table 14: Degree of equivalence to the CRV for SWEMA anemometer; laboratories not passing the test are marked with red background;

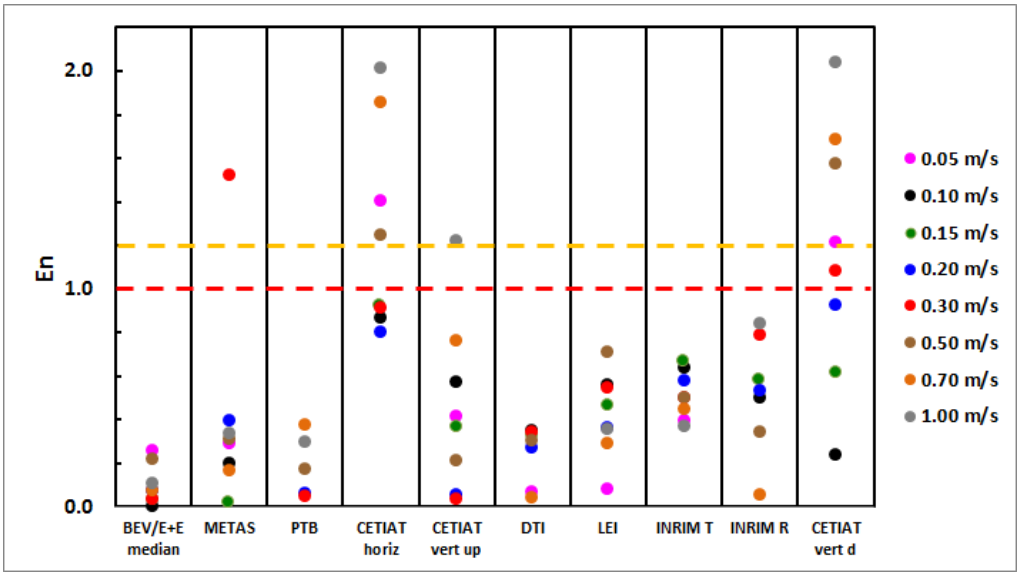

Figure 6: E_n values for the comparison of laboratory values to the CRV for SWEMA

8.2 EE75

The equivalence test of the laboratory results to the CRV are presented in Table 15 and Figure 7 for the EE75 anemometer. The measurement of INRIM T and R, the second measurement of CETIAT "horizontal" and the measurement of CTIAT "vertical down" are not included in the determination of the CRV because of the instability of the anemometer. However, they are implemented in the consideration of the degree of equivalence even though most of these values did not pass the $|E_i|$ criterion as it can be seen in Table 15. They are just mentioned for completeness. The measurement results that suffer from the large instability are marked with the dotted background in Table 15 and the gray background Figure 7.

In total five measurement results do not pass the equivalence test. For the velocities of 0.1 m/s and 0.15 m/s, the equivalence test is not passed by CETIAT vertical up and LEI and for 1 m/s it is not passed by METAS. Further it has to be mentioned in addition that the median value of the pilot laboratory does not pass the chi-squared test but the equivalence test is passed. The reason for this is the large uncertainty of the comparison reference value at the lowest velocity.

Degree of equivalence												
v [m/s]	BEV/E+E (median)		METAS		PTB		CETIAT - hor		CETIAT - vert up		DTI	
	d_i	U(k=2)	d_i	U(k=2)	d_i	U(k=2)	d_i	U(k=2)	d_i	U(k=2)	d_i	U(k=2)
0.05												
0.1	0.0947	0.1357					0.0019	0.0229	0.1386	0.0411	0.0188	0.2905
0.15	0.0127	0.0639	0.0372	0.1539			0.0215	0.0393	0.0692	0.0477	0.0735	0.1745
0.2	0.0160	0.0498	0.0648	0.1533	0.0281	0.0519	0.0114	0.0345	0.0242	0.0393	0.0415	0.1202
0.3	0.0117	0.0408	0.0548	0.1053	0.0076	0.0366	0.0061	0.0238	0.0057	0.0282	0.0510	0.0750
0.5	0.0009	0.0194	0.0146	0.0411	0.0100	0.0267	0.0103	0.0194	0.0062	0.0225	0.0428	0.0455
0.7	0.0024	0.0165	0.0345	0.0557	0.0056	0.0208	0.0051	0.0189	0.0007	0.0206	0.0306	0.0350
1	0.0053	0.0238	0.0481	0.0277	0.0092	0.0203	0.0070	0.0176	0.0056	0.0225		

v [m/s]	LEI		INRIM T		INRIM R		CETIAT hor		CETIAT vert d	
	d_i	U(k=2)	d_i	U(k=2)	d_i	U(k=2)	d_i	U(k=2)	d_i	U(k=2)
0.05										
0.1	0.0783	0.0117	0.1468	0.2842	0.0928	0.3214	0.0800	0.0333	0.0359	0.0345
0.15	0.0878	0.0588	0.1089	0.2377	0.0597	0.2311	0.1059	0.0400	0.0589	0.0404
0.2	0.0478	0.0443	0.0796	0.1766	0.0374	0.1469	0.0786	0.0339	0.0621	0.0341
0.3	0.0339	0.0465	0.0670	0.1067	0.0627	0.1033	0.0916	0.0241	0.0928	0.0243
0.5	0.0130	0.0387	0.1008	0.0570	0.0435	0.0696	0.0916	0.0318	0.0921	0.0320
0.7	0.0220	0.0431	0.0724	0.0403	0.0499	0.0498	0.1006	0.0183	0.0874	0.0184
1	0.0185	0.0361	0.0703	0.0340	0.0464	0.0361	0.0935	0.0181	0.0881	0.0181

Table 15: Degree of equivalence to the CRV for EE75 anemometer; laboratories not passing the test are marked with red background; measurement results that suffer from the large drift due to pollution are marked with dotted background

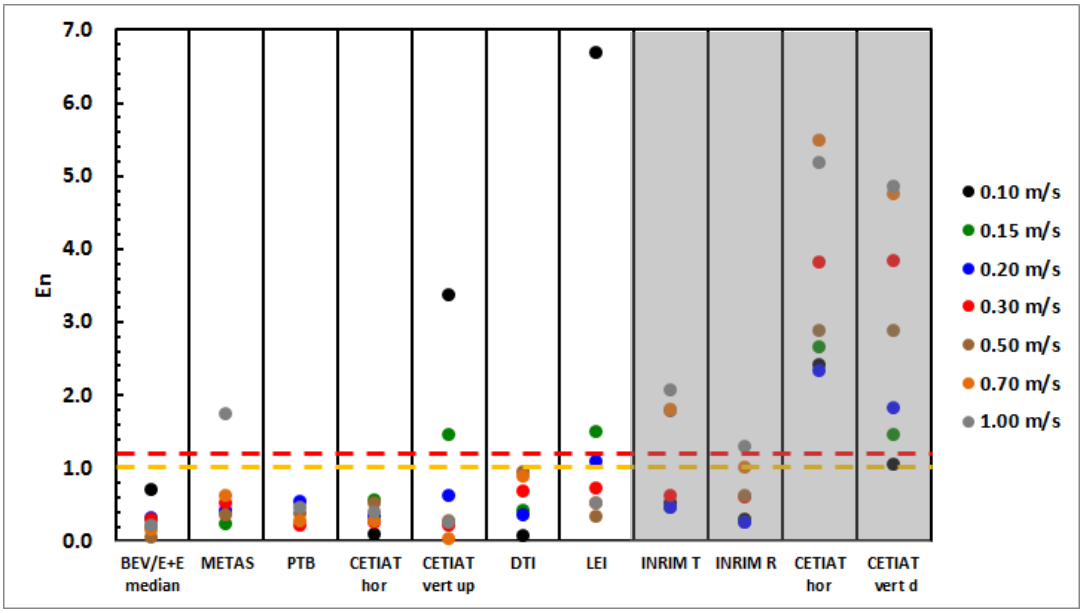

Figure 7: En values for the comparison of laboratory values to the CRV for EE75;

9 Determination of the "lab-to-lab" equivalence

The inter-comparison of the different laboratories with each other is done according to the formulas presented in chapter 8 (equ. 8.5 - 8.8). The results are presented in Table 16 for the SWEMA and in Table 17: for the EE75 anemometer. For each velocity, the difference $d_{i,j}$ between the laboratory results are cited and marked with a red background, if $\left|E_{i,j}\right| > 1$.

For the SWEMA anemometer, the degree of equivalence of the laboratory results is quite well for almost all data. The data from CETIAT concerning the different orientations of the wind tunnel have some inconsistencies. The second inconsistency is observed at 0.3 m/s in the measurement data of METAS.

For the EE75 anemometer, the degree of equivalence is again pretty good for most of the data. The inconsistencies concerning the different orientations of the CETIAT measurement results are observed also with this anemometer. Additionally, some inconsistencies between BEV/E+E and LEI for velocities of 0.1 m/s, 0.15 m/s and 0.2 m/s and between BEV/E+E and DTI for velocities of 0.5 m/s and 0.7 m/s are observed. At the highest velocity of 1 m/s the measurement results of METAS does not match to the other institutes.

The above mentioned inconsistencies are comparable to the results of the chi-squared test.

v [m/s] 0.05	BEV/E+E	Metas	PTB	Cetiat hor	Cetiat vert u	DTI	LEI	INRIM T	INRIM R	CETIAT vert d
BEV/E+E		0.0122		0.1667	0.0357	0.0834	0.1065	0.4281		0.1200
Metas	0.0122			0.1789	0.0235	0.0712	0.0944	0.4159		0.1321
PTB										
CETIAT hor	0.1667	0.1789			0.2024	0.2501	0.2732	0.5948		0.0468
Cetiat vert up	0.0357	0.0235		0.2024		0.0477	0.0709	0.3924		0.1556
DTI	0.0834	0.0712		0.2501	0.0477		0.0231	0.3446		0.2034
LEI	0.1065	0.0944		0.2732	0.0709	0.0231		0.3215		0.2265
INRIM T	0.4281	0.4159		0.5948	0.3924	0.3446	0.3215			0.5480
INRIM R										
CETIAT vert d	0.1200	0.1321		0.0468	0.1556	0.2034	0.2265	0.5480		

v [m/s] 0.3	BEV/E+E	Metas	PTB	Cetiat hor	Cetiat vert u	DTI	LEI	INRIM T	INRIM R	CETIAT vert d
BEV/E+E		0.0655	0.0012	0.0266	0.0028	0.0250	0.0188	0.0739	0.0912	0.0316
Metas	0.0655		0.0667	0.0390	0.0628	0.0905	0.0843	0.1394	0.1567	0.0339
PTB	0.0012	0.0667		0.0277	0.0039	0.0239	0.0176	0.0727	0.0900	0.0328
CETIAT hor	0.0266	0.0390	0.0277		0.0238	0.0516	0.0453	0.1005	0.1178	0.0050
Cetiat vert up	0.0028	0.0628	0.0039	0.0238		0.0278	0.0215	0.0766	0.0939	0.0289
DTI	0.0250	0.0905	0.0239	0.0516	0.0278		0.0062	0.0489	0.0662	0.0566
LEI	0.0188	0.0843	0.0176	0.0453	0.0215	0.0062		0.0551	0.0724	0.0504
INRIM T	0.0739	0.1394	0.0727	0.1005	0.0766	0.0489	0.0551		0.0173	0.1055
INRIM R	0.0912	0.1567	0.0900	0.1178	0.0939	0.0662	0.0724	0.0173		0.1228
CETIAT vert d	0.0316	0.0339	0.0328	0.0050	0.0289	0.0566	0.0504	0.1055	0.1228	

v [m/s] 0.1	BEV/E+E	Metas	PTB	CETIAT hor	Cetiat vert u	DTI	LEI	INRIM T	INRIM R	CETIAT vert d
BEV/E+E		0.1290		0.0559	0.0415	0.0792	0.0376	0.2861	0.2109	0.0166
Metas	0.1290			0.1850	0.0875	0.0499	0.0914	0.1571	0.0819	0.1456
PTB										
CETIAT hor	0.0559	0.1850			0.0974	0.1351	0.0936	0.3421	0.2668	0.0393
Cetiat vert up	0.0415	0.0875		0.0974		0.0377	0.0039	0.2446	0.1694	0.0581
DTI	0.0792	0.0499		0.1351	0.0377		0.0415	0.2070	0.1317	0.0958
LEI	0.0376	0.0914		0.0936	0.0039	0.0415		0.2485	0.1733	0.0542
INRIM T	0.2861	0.1571		0.3421	0.2446	0.2070	0.2485		0.0752	0.3027
INRIM R	0.2109	0.0819		0.2668	0.1694	0.1317	0.1733	0.0752		0.2275
CETIAT vert d	0.0166	0.1456		0.0393	0.0581	0.0958	0.0542	0.3027	0.2275	

v [m/s] 0.5	BEV/E+E	Metas	PTB	CETIAT hor	Cetiat vert u	DTI	LEI	INRIM T	INRIM R	CETIAT vert d
BEV/E+E		0.0188	0.0047	0.0325	0.0134	0.0055	0.0093	0.0361	0.0141	0.0425
Metas	0.0188		0.0140	0.0137	0.0053	0.0243	0.0281	0.0548	0.0329	0.0238
PTB	0.0047	0.0140		0.0278	0.0087	0.0103	0.0141	0.0408	0.0189	0.0378
CETIAT hor	0.0325	0.0137	0.0278		0.0191	0.0380	0.0418	0.0686	0.0466	0.0100
Cetiat vert up	0.0134	0.0053	0.0087	0.0191		0.0189	0.0228	0.0495	0.0275	0.0291
DTI	0.0055	0.0243	0.0103	0.0380	0.0189		0.0038	0.0305	0.0086	0.0480
LEI	0.0093	0.0281	0.0141	0.0418	0.0228	0.0038		0.0267	0.0048	0.0519
INRIM T	0.0361	0.0548	0.0408	0.0686	0.0495	0.0305	0.0267		0.0219	0.0786
INRIM R	0.0141	0.0329	0.0189	0.0466	0.0275	0.0086	0.0048	0.0219		0.0566
CETIAT vert d	0.0425	0.0238	0.0378	0.0100	0.0291	0.0480	0.0519	0.0786	0.0566	

v [m/s] 0.15	BEV/E+E	Metas	PTB	CETIAT hor	Cetiat vert u	DTI	LEI	INRIM T	INRIM R	CETIAT vert d
BEV/E+E		0.0024		0.0397	0.0127	0.0474	0.0197	0.1570	0.1343	0.0289
Metas	0.0024			0.0421	0.0103	0.0449	0.0173	0.1545	0.1319	0.0313
PTB										
CETIAT hor	0.0397	0.0421			0.0524	0.0871	0.0595	0.1967	0.1740	0.0109
Cetiat vert up	0.0127	0.0103		0.0524		0.0346	0.0070	0.1442	0.1216	0.0416
DTI	0.0474	0.0449		0.0871	0.0346		0.0276	0.1096	0.0869	0.0762
LEI	0.0197	0.0173		0.0595	0.0070	0.0276		0.1372	0.1145	0.0486
INRIM T	0.1570	0.1545		0.1967	0.1442	0.1096	0.1372		0.0227	0.1858
INRIM R	0.1343	0.1319		0.1740	0.1216	0.0869	0.1145	0.0227		0.1631
CETIAT vert d	0.0289	0.0313		0.0109	0.0416	0.0762	0.0486	0.1858	0.1631	

v [m/s] 0.7	BEV/E+E	Metas	PTB	CETIAT hor	Cetiat vert u	DTI	LEI	INRIM T	INRIM R	CETIAT vert d
BEV/E+E		0.0080	0.0122	0.0385	0.0154	0.0004	0.0054	0.0260	0.0008	0.0357
Metas	0.0080		0.0042	0.0305	0.0074	0.0076	0.0134	0.0340	0.0088	0.0277
PTB	0.0122	0.0042		0.0262	0.0031	0.0118	0.0176	0.0382	0.0130	0.0235
CETIAT hor	0.0385	0.0305	0.0262		0.0231	0.0380	0.0439	0.0644	0.0392	0.0028
Cetiat vert up	0.0154	0.0074	0.0031	0.0231		0.0149	0.0208	0.0413	0.0161	0.0204
DTI	0.0004	0.0076	0.0118	0.0380	0.0149		0.0058	0.0264	0.0012	0.0353
LEI	0.0054	0.0134	0.0176	0.0439	0.0208	0.0058		0.0206	0.0046	0.0411
INRIM T	0.0260	0.0340	0.0382	0.0644	0.0413	0.0264	0.0206		0.0252	0.0617
INRIM R	0.0008	0.0088	0.0130	0.0392	0.0161	0.0012	0.0046	0.0252		0.0365
CETIAT vert d	0.0357	0.0277	0.0235	0.0028	0.0204	0.0353	0.0411	0.0617	0.0365	

v [m/s] 0.2	BEV/E+E	Metas	PTB	CETIAT hor	Cetiat vert u	DTI	LEI	INRIM T	INRIM R	CETIAT vert d
BEV/E+E		0.0654	0.0046	0.0348	0.0026	0.0261	0.0123	0.1015	0.0889	0.0407
Metas	0.0654		0.0700	0.0306	0.0629	0.0915	0.0777	0.1669	0.1543	0.0247
PTB	0.0046	0.0700		0.0394	0.0071	0.0216	0.0077	0.0969	0.0844	0.0452
CETIAT hor	0.0348	0.0306	0.0394		0.0323	0.0609	0.0471	0.1363	0.1237	0.0059
Cetiat vert up	0.0026	0.0629	0.0071	0.0323		0.0287	0.0149	0.1040	0.0915	0.0381
DTI	0.0261	0.0915	0.0216	0.0609	0.0287		0.0138	0.0753	0.0628	0.0668
LEI	0.0123	0.0777	0.0077	0.0471	0.0149	0.0138		0.0892	0.0766	0.0530
INRIM T	0.1015	0.1669	0.0969	0.1363	0.1040	0.0753	0.0892		0.0125	0.1421
INRIM R	0.0889	0.1543	0.0844	0.1237	0.0915	0.0628	0.0766	0.0125		0.1296
CETIAT vert d	0.0407	0.0247	0.0452	0.0059	0.0381	0.0668	0.0530	0.1421	0.1296	

v [m/s] 1	BEV/E+E	Metas	PTB	CETIAT hor	Cetiat vert u	DTI	LEI	INRIM T	INRIM R	CETIAT vert d
BEV/E+E		0.0063	0.0099	0.0413	0.0219		0.0041	0.0147	0.0311	0.0344
Metas	0.0063		0.0162	0.0476	0.0282		0.0023	0.0083	0.0375	0.0407
PTB	0.0099	0.0162		0.0314	0.0120		0.0139	0.0245	0.0213	0.0245
CETIAT hor	0.0413	0.0476	0.0314		0.0194		0.0453	0.0559	0.0101	0.0069
Cetiat vert up	0.0219	0.0282	0.0120	0.0194			0.0260	0.0365	0.0092	0.0125
DTI										
LEI	0.0041	0.0023	0.0139	0.0453	0.0260			0.0106	0.0352	0.0384
INRIM T	0.0147	0.0083	0.0245	0.0559	0.0365		0.0106		0.0458	0.0490
INRIM R	0.0311	0.0375	0.0213	0.0101	0.0092		0.0352	0.0458		0.0032
CETIAT vert d	0.0344	0.0407	0.0245	0.0069	0.0125		0.0384	0.0490	0.0032	

Table 16: Degree of equivalence between laboratories of each velocity for the SWEMA anemometer

v = 0.05 [m/s]	BEV/E+E	METAS	PTB	BEV/E+E	CETIAT hor	CETIAT vert u	DTI	LEI	BEV/E+E
BEV/E+E									
METAS									
PTB									
BEV/E+E									
CETIAT hor						0.3946			
CETIAT vert u					0.3946				
DTI									
LEI									
BEV/E+E									

v = 0.3 [m/s]	BEV/E+E	METAS	PTB	BEV/E+E	CETIAT hor	CETIAT vert u	DTI	LEI	BEV/E+E
BEV/E+E		0.0659	0.0187	0.0031	0.005	0.0169	0.0621	0.0451	0.0011
METAS	0.0659		0.0472	0.069	0.0609	0.049	0.0038	0.0208	0.067
PTB	0.0187	0.0472		0.0218	0.0137	0.0018	0.0434	0.0264	0.0198
BEV/E+E	0.0031	0.069	0.0218		0.0081	0.02	0.0652	0.0482	0.002
CETIAT hor	0.005	0.0609	0.0137	0.0081		0.0119	0.0571	0.0401	0.0061
CETIAT vert u	0.0169	0.049	0.0018	0.02	0.0119		0.0452	0.0282	0.018
DTI	0.0621	0.0038	0.0434	0.0652	0.0571	0.0452		0.017	0.0632
LEI	0.0451	0.0208	0.0264	0.0482	0.0401	0.0282	0.017		0.0462
BEV/E+E	0.0011	0.067	0.0198	0.002	0.0061	0.018	0.0632	0.0462	

v = 0.1 [m/s]	BEV/E+E	METAS	PTB	BEV/E+E	CETIAT hor	CETIAT vert u	DTI	LEI	BEV/E+E
BEV/E+E				0.0161	0.0907	0.2312	0.1115	0.1709	0.001
METAS									
PTB									
BEV/E+E	0.0161				0.1068	0.2473	0.1276	0.187	0.0171
CETIAT hor	0.0907			0.1068		0.1405	0.0208	0.0802	0.0897
CETIAT vert u	0.2312			0.2473	0.1405		0.1197	0.0603	0.2302
DTI	0.1115			0.1276	0.0208	0.1197		0.0594	0.1105
LEI	0.1709			0.187	0.0802	0.0603	0.0594		0.1699
BEV/E+E	0.001			0.0171	0.0897	0.2302	0.1105	0.1699	

v = 0.5 [m/s]	BEV/E+E	METAS	PTB	BEV/E+E	CETIAT hor	CETIAT vert u	DTI	LEI	BEV/E+E
BEV/E+E		0.008	0.0167	0.0002	0.0036	0.0004	0.0494	0.0196	0.0126
METAS	0.008		0.0247	0.0082	0.0044	0.0084	0.0574	0.0276	0.0206
PTB	0.0167	0.0247		0.0165	0.0203	0.0163	0.0327	0.0029	0.0041
BEV/E+E	0.0002	0.0082	0.0165		0.0038	0.0002	0.0492	0.0194	0.0124
CETIAT hor	0.0036	0.0044	0.0203	0.0038		0.004	0.053	0.0232	0.0162
CETIAT vert u	0.0004	0.0084	0.0163	0.0002	0.004		0.049	0.0192	0.0122
DTI	0.0494	0.0574	0.0327	0.0492	0.053	0.049		0.0298	0.0368
LEI	0.0196	0.0276	0.0029	0.0194	0.0232	0.0192	0.0298		0.007
BEV/E+E	0.0126	0.0206	0.0041	0.0124	0.0162	0.0122	0.0368	0.007	

v = 0.15 [m/s]	BEV/E+E	METAS	PTB	BEV/E+E	CETIAT hor	CETIAT vert u	DTI	LEI	BEV/E+E
BEV/E+E		0.0266		0.0041	0.0322	0.0798	0.0841	0.0985	0.0069
METAS	0.0266			0.0225	0.0588	0.1064	0.1107	0.1251	0.0197
PTB									
BEV/E+E	0.0041	0.0225			0.0363	0.0839	0.0882	0.1026	0.0028
CETIAT hor	0.0322	0.0588		0.0363		0.0476	0.0519	0.0663	0.0391
CETIAT vert u	0.0798	0.1064		0.0839	0.0476		0.0043	0.0187	0.0867
DTI	0.0841	0.1107		0.0882	0.0519	0.0043		0.0144	0.091
LEI	0.0985	0.1251		0.1026	0.0663	0.0187	0.0144		0.1054
BEV/E+E	0.0069	0.0197		0.0028	0.0391	0.0867	0.091	0.1054	

v = 0.7 [m/s]	BEV/E+E	METAS	PTB	BEV/E+E	CETIAT hor	CETIAT vert u	DTI	LEI	BEV/E+E
BEV/E+E		0.0436	0.0147	0.0008	0.004	0.0098	0.0397	0.0311	0.0169
METAS	0.0436		0.0289	0.0444	0.0396	0.0338	0.0039	0.0125	0.0267
PTB	0.0147	0.0289		0.0155	0.0107	0.0049	0.025	0.0164	0.0022
BEV/E+E	0.0008	0.0444	0.0155		0.0048	0.0106	0.0405	0.0319	0.0177
CETIAT hor	0.004	0.0396	0.0107	0.0048		0.0058	0.0357	0.0271	0.0129
CETIAT vert u	0.0098	0.0338	0.0049	0.0106	0.0058		0.0299	0.0213	0.0071
DTI	0.0397	0.0039	0.025	0.0405	0.0357	0.0299		0.0086	0.0228
LEI	0.0311	0.0125	0.0164	0.0319	0.0271	0.0213	0.0086		0.0142
BEV/E+E	0.0169	0.0267	0.0022	0.0177	0.0129	0.0071	0.0228	0.0142	

v = 0.2 [m/s]	BEV/E+E	METAS	PTB	BEV/E+E	CETIAT hor	CETIAT vert u	DTI	LEI	BEV/E+E
BEV/E+E		0.0508	0.0421	0.004	0.0027	0.0382	0.0555	0.0618	0.0093
METAS	0.0508		0.0929	0.0468	0.0535	0.089	0.1063	0.1126	0.0415
PTB	0.0421	0.0929		0.0461	0.0394	0.0039	0.0134	0.0197	0.0514
BEV/E+E	0.004	0.0468	0.0461		0.0067	0.0422	0.0595	0.0658	0.0053
CETIAT hor	0.0027	0.0535	0.0394	0.0067		0.0355	0.0528	0.0591	0.012
CETIAT vert u	0.0382	0.089	0.0039	0.0422	0.0355		0.0173	0.0236	0.0475
DTI	0.0555	0.1063	0.0134	0.0595	0.0528	0.0173		0.0063	0.0648
LEI	0.0618	0.1126	0.0197	0.0658	0.0591	0.0236	0.0063		0.0711
BEV/E+E	0.0093	0.0415	0.0514	0.0053	0.012	0.0475	0.0648	0.0711	

v = 1 [m/s]	BEV/E+E	METAS	PTB	BEV/E+E	CETIAT hor	CETIAT vert u	DTI	LEI	BEV/E+E
BEV/E+E		0.0505	0.0067	0.0008	0.0045	0.0031		0.021	0.0147
METAS	0.0505		0.0572	0.0497	0.055	0.0536		0.0295	0.0358
PTB	0.0067	0.0572		0.0075	0.0022	0.0036		0.0277	0.0214
BEV/E+E	0.0008	0.0497	0.0075		0.0053	0.0039		0.0202	0.0139
CETIAT hor	0.0045	0.055	0.0022	0.0053		0.0014		0.0255	0.0192
CETIAT vert u	0.0031	0.0536	0.0036	0.0039	0.0014			0.0241	0.0178
DTI									
LEI	0.021	0.0295	0.0277	0.0202	0.0255	0.0241			0.0063
BEV/E+E	0.0147	0.0358	0.0214	0.0139	0.0192	0.0178		0.0063	

Table 17: Degree of equivalence between laboratories for each velocity for the EE75 anemometer

10 Conclusion

The EURAMET comparison P1225 - Intercomparison of very low air speed standard facilities (0.05 m/s – 1 m/s) - has been successfully finished. It was carried out with two thermal anemometers as transfer standards, namely the SWEMA and the EE75 anemometer. The stability of the SWEMA was sufficiently good over the whole period of the comparison. In contrast, the EE75 transfer standard suffered from a large change within the last section of the comparison. The data of this section are excluded from the calculation of the comparison value. They are only mentioned for completeness.

The measurement results from the different orientations did not deliver a clear result. For the SWEMA anemometer the data from the vertical up orientation fulfill the equivalence test while for the EE75 anemometer the horizontal configuration passes the test. The two anemometers differ with respect to their geometry. The SWEMA anemometer is an omnidirectional anemometer. It therefore sums up the flow components of all directions. While the EE75 anemometer is planar type and measures only one component of the flow vector. For low air speeds the measurement results of the two anemometers slightly differ regarding the different orientations. The reason for this could be a small contribution from natural thermal convection which originates either from the anemometers themselves or from the wind tunnel. In either case the thermal convection has to be carefully analyzed, especially its contribution to a calibration procedure. But anyway, these assumptions have to be verified with independent experiments, e.g. LDA measurements of all components of the flow vector or with the help of particle image velocimetry (PIV) where the different components can be made visible.

In conclusion, the comparison was successfully carried out and the calculated comparison reference values represent very well the results of the majority of the institutes. Regarding the lab-to-lab comparison, it is obvious that for some air speeds and some laboratories the measurement results show some inconsistencies. Therefore still some work has to be done in order to further optimize the used calibration procedures.

11 References

[1] Guidelines for CIPM key comparison

[2] Comparison protocol organization for EURAMET TC flow – January 2015

[3] Cox, M. G., The Evaluation of Key Comparison Data, Metrologia 39, 589-595, 2002

[4] Cox, M.G., The evaluation of key comparison data: determining the largest consistent subset, Metrologia 44, 187-200, 2007

12 Appendix – Laboratory Information

	type	range	uncertainty	dimensions measurung section	reference
BEV/E+E	windtunnel (Eiffler)	0.04 m/s to 2 m/s	0.004 m/s + 0.0047*v	0.25x0.25x0.30 m³	LDA
Metas	tow tank	0.02 m/s to 13 m/s	(0.1 + 0.5/v) %	2.40x2.40x30 m³	Length, time
PTB	windtunnel (Eiffler)	0.2 m/s to 40 m/s	(0.01 + 0.0045 *v)	diameter. 0.180 m, measuring section 0.51 m	LDA
CETIAT	windtunnel (Göttinger)	0.05 m/s to 2 m/s	0.006 m/s + 0.006*v	0.25x0.25x0.80 m³	LDA
DTI	tow tank	0.05 m/s to 0.7 m/s	0.02 m/s	diameter 0.5 m, measuring section 8 m	LDA
INRIM	rotary arm (entrainment)	0.1 m/s to 5 m/s	8 % to 0.6 %	N/A	Length, time, LDA
	tow tank (entrainment)	0.05 m/s to 1.2 m/s	4 % to 0.8 %	2x0.8 m²	Length, time
LEI	windtunnel (Göttinger)	0.05 m/s to 1 m/s	(8 - 1.9) %	diameter 0.4 m, measuren section 2.02 m	LDA