



*Measuring-Network of Wind Energy Institutes*

16ac01

# Anemometer Calibration Proficiency Test

Report for IECRE

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16ac01 Report

# Acknowledgement

This project has been carried out in the framework of MEASNET, in close collaboration with the SG551 group of IECRE. The author wishes to recognize the collaboration of the Measnet secretariat and the SG551 convener in the development of the Proficiency Test.

## Abstract

This document presents the results of the 16ac01 proficiency test organized by Measnet in collaboration with IECRE. This proficiency test is organized according to the Measnet Anemometer Calibration Procedure, version 2, which in its annex A establishes the methodology for the Anemometer Calibration Proficiency Tests.

The goal of the Proficiency Test is to verify the accuracy of cup anemometer calibration results from the participant institutes. Since there is not a standard for wind speed, the comparison between wind tunnels is performed by sending the same cup anemometers to these wind tunnels and comparing the calibration results.

The laboratories participating in this Proficiency test are:

- Deutsche WindGuard Wind Tunnel Services GmbH
- ProfEC Ventus GmbH
- Centre Scientifique et Technique du Bâtiment CSTB
- International Wind Engineering IWE
- Center for Renewable Energy Sources CRES
- WIND-consult GmbH
- Ammonit Wind Tunnel GmbH
- SOH Wind Engineering LLC
- Svend Ole Hansen ApS
- Laboratórios Especializados em Eletroeletrônica Calibração e Ensaios PUCRS
- Instituto Universitario "Ignacio Da Riva" IDR/UPM

The results have been analyzed by IDR/UPM acting as the conductor of the proficiency test. Measurements have been taken in order to prevent the conductor from getting the results of the other institutions before having presented to the Measnet secretariat its own results.

The Proficiency test reference wind speed is determined by the calibration results of the participant institutes. The reference wind speed is used to determine whether institutes comply with the Proficiency Test requirement for anemometer calibration uncertainty.

This report describes the Round Robin results of the participating institute, including the determination of the reference wind speed.

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# 1. Introduction

Within the framework of the MEASNET network internal quality evaluation programme, the collaboration with the IECRE organization and the consideration of proficiency testing as a service offered to its customers, an anemometer calibration Round Robin exercise was organized and performed. The following institutes have participated in this Round Robin:

- Deutsche WindGuard Wind Tunnel Services GmbH
- ProfEC Ventus GmbH
- Centre Scientifique et Technique du Bâtiment CSTB
- International Wind Engineering IWE
- Center for Renewable Energy Sources CRES
- WIND-consult GmbH
- Ammonit Wind Tunnel GmbH
- SOH Wind Engineering LLC
- Svend Ole Hansen ApS
- Laboratórios Especializados em Eletroeletrônica Calibração e Ensaios PUCRS
- Instituto Universitario “Ignacio Da Riva” IDR/UPM

The calibration results have been analysed by IDR/UPM according to the MEASNET Anemometer Calibration Round robin rules described in Annex A of its procedure. Measurements have been taken in order to prevent the conductor from getting the results of the other institutions before having presented to the Measnet secretariat its own results. Apart from MEASNET institutes, other institutes could participate in the Round Robin.

Some institutes participate with more than one set of calibration results, these sets could be “correlated” which would influence the reference wind speed. Therefore only one of the calibration sets of each such institutes will be defined as ‘primary’ and allowed to contribute to the reference wind speed. The other datasets are marked as ‘secondary’ datasets and evaluated against the proficiency test reference wind speed.

The same procedure is applied for those laboratories that have close relations among them. This is the case of SOH Wind Engineering LLC - Svend Ole Hansen ApS and WIND-consult GmbH - Ammonit Wind Tunnel GmbH.

In these cases the institutions involved have identified their ‘primary’ results.

## 1.1. Time Line

### Phase 1:

Participants apply for participation	21.03.2016	15.06.2016	63 days
Measnet informs participants		15.06.2016	+0 day

### Phase 2:

Conductor send anemometers and Participants calibrates the Anemometers	16.06.2016	16.04.2017	220 days
Participants uploads results		Latest 19.04.2017	+3 days
Measnet grants data access to results for conductor		20.04.2017	+1 day
Conductor analysis results	20.04.2017	28.04.2017	7 days
Conductor uploads results		Latest 01.05.2017	+1 day
Discussion	02.05.2017	15.05.2017	+10 days

Note: This document has been re-formatted after its first creation. Therefore its date is not linked to the actual progress of the Proficiency test.

## 1.2. Cup Anemometers

Two cup anemometers have been used in the MEASNET Round Robin exercise on cup anemometer calibration:

- Thies First class advanced, serial number CA-2016-001
- Windsensor P2546A-OPR, serial number CA-2016-002

Original serial numbers for the anemometers have been covered, in order to allow the same anemometers to be used in further exercises while keeping the participants unaware of the actual anemometer used and therefore unaware of previous results.

These anemometers have been calibrated at each of the participating institutes according to their own procedures. As first and last calibration the anemometers were calibrated in the wind tunnel of IDR/UPM in Madrid. Comparison of these pre- and post- round robin calibration shows that the anemometers did not change substantially specs during the round robin.

## 2. Results provided by the institutions

The results submitted by the various institutes that form the Proficiency Test Reference Wind Speed are presented in the table 1 below.

Results are presented anonymized and the date of calibration is also omitted in order to assure the confidentiality of each laboratory's results.

Table 1: Results provided by the participants to form the Reference Wind Speed.

	Institute	A	B	C	D	E	F	G	H	I
Risø CA-2016-002	slope [(m/s)/Hz]	0.61471	0.61594	0.61573	0.62390	0.61770	0.61759	0.61785	0.61699	0.61010
	offset [m/s]	0.27300	0.21470	0.28300	0.22600	0.24000	0.23866	0.23808	0.22679	0.44990
Thies Clima CA-2016-001	slope [(m/s)/Hz]	0.04620	0.04611	0.04587	0.04699	0.04600	0.04616	0.04608	0.04600	0.04550
	offset [m/s]	0.21500	0.23010	0.23100	0.23800	0.24000	0.25325	0.26715	0.27285	0.47990

The results correspond to calibrations performed from August 2<sup>nd</sup>, 2016 to May 27<sup>th</sup>, 2017. Results were sent to the Measnet secretariat from May 22<sup>nd</sup>, 2017 to May 27<sup>th</sup>, 2017, along with the corresponding calibration certificates in PDF format.

## 3. Evaluation of the results

### 3.1. Cup Anemometers integrity check.

Both anemometers were checked before and after the Proficiency test by the IDR/UPM. The results are shown in the table 2.

Table 2: Results of the integrity check calibrations.

<b>7 m/s</b>		output freq	Post RR	Pre RR	Difference	Difference
	s.n.	[Hz]	[m/s]	[m/s]	[m/s]	[%]
WindSensor	CA-2016-002	10.92	6.98473	6.98980	0.00507	0.073
Thies Clima	CA-2016-001	145.99	6.99431	7.02938	0.03507	0.501

  

<b>10m/s</b>		output freq	Pre RR	Post RR	Difference	Difference
	s.n.	[Hz]	[m/s]	[m/s]	[m/s]	[%]
WindSensor	CA-2016-002	15.78	9.99030	9.98429	-0.00602	-0.060
Thies Clima	CA-2016-001	211.07	9.99307	10.03725	0.04418	0.442

  

<b>13m/s</b>		output freq	Pre RR	Post RR	Difference	Difference
	s.n.	[Hz]	[m/s]	[m/s]	[m/s]	[%]
WindSensor	CA-2016-002	20.65	12.99588	12.97877	-0.01711	-0.132
Thies Clima	CA-2016-001	276.14	12.99183	13.04512	0.05329	0.410

Some deviations have been found in the Thies Clima anemometer. These differences could be attributed to the running-in of the bearings.

Therefore those laboratories that show very different performances between both anemometers might have to take caution in the analysis of these proficiency test results.



### 3.2. Anemometer output frequencies.

For each anemometer and each participant three output frequencies have been determined, corresponding to wind speeds of about 7, 10 and 13 m/s.

Table 3: Output frequencies corresponding to 7, 10 and 13 m/s.

7 m/s	Institute	A	B	C	D	E	F	G	H	I
	WindSensor CA-2016-002	10.943	11.016	10.909	10.858	10.944	10.948	10.944	10.978	10.736
	Thies Clima CA-2016-001	146.849	146.821	147.569	143.903	146.957	146.160	146.112	146.230	143.299

10 m/s	Institute	A	B	C	D	E	F	G	H	I
	WindSensor CA-2016-002	15.824	15.887	15.781	15.666	15.801	15.806	15.800	15.840	15.653
	Thies Clima CA-2016-001	211.778	211.882	212.971	207.746	212.174	211.151	211.216	211.441	209.233

13 m/s	Institute	A	B	C	D	E	F	G	H	I
	WindSensor CA-2016-002	20.704	20.757	20.654	20.474	20.657	20.663	20.655	20.702	20.571
	Thies Clima CA-2016-001	276.708	276.944	278.374	271.590	277.391	276.143	276.321	276.653	275.167

From these frequencies an average frequency at each wind speed and for each anemometer is calculated. These frequencies are used in the next steps to calculate the wind velocities for each laboratory and compare the results in terms of wind velocity. Only the values declared as "primary" are taken into account in this phase.

### 3.3. Calculation of wind speeds.

For each anemometer and for each of the three frequencies the wind speeds according to the calibration results of the institutes have been calculated. Each wind speed is assumed to have a standard uncertainty of 1%.

Table 4: Wind speeds for each laboratory for averaged speeds of 7, 10 and 13 m/s.

Calculated Wind speeds (Average 7 m/s)										
	output freq	A	B	C	D	E	F	G	H	I
<b>WindSensor</b>	10.92 Hz	6.985	6.940	7.007	7.039	6.985	6.982	6.985	6.964	7.112
<b>Thies Clima</b>	145.99 Hz	6.960	6.962	6.928	7.098	6.955	6.992	6.994	6.989	7.122

Calculated Wind speeds (Average 10 m/s)										
	output freq	A	B	C	D	E	F	G	H	I
<b>WindSensor</b>	15.78 Hz	9.976	9.937	10.002	10.074	9.990	9.987	9.990	9.965	10.080
<b>Thies Clima</b>	211.07 Hz	9.967	9.962	9.913	10.156	9.949	9.996	9.993	9.983	10.083

Calculated Wind speeds (Average 13 m/s)										
	output freq	A	B	C	D	E	F	G	H	I
<b>WindSensor</b>	20.65 Hz	12.966	12.933	12.997	13.109	12.995	12.991	12.996	12.967	13.048
<b>Thies Clima</b>	276.14 Hz	12.974	12.963	12.898	13.214	12.943	13.000	12.992	12.977	13.044

As a first estimate of the Proficiency test reference wind speed the results of all institutes per anemometer and per output frequency have been averaged. The standard uncertainty of this reference wind speed is assumed to be  $(1/\sqrt{N})\%$  in which N is the number of institutes that calibrated the regarded anemometer.

### 3.4. Calculation of deviation in percentage and outliers discard.

The deviation of each laboratory from the averaged wind speed is expressed as a percentage of the wind speed.

Table 5: Wind speeds deviation for each laboratory.

Differences in % (Velocity average = 7m/s)									
	A	B	C	D	E	F	G	H	I
WindSensor CA-2016-002	-0.21%	-0.85%	0.09%	0.55%	-0.21%	-0.25%	-0.22%	-0.51%	1.60%
Thies Clima CA-2016-001	-0.57%	-0.55%	-1.04%	1.40%	-0.64%	-0.11%	-0.08%	-0.16%	1.75%

Differences in % (Velocity average = 10m/s)									
	A	B	C	D	E	F	G	H	I
WindSensor CA-2016-002	-0.24%	-0.63%	0.02%	0.74%	-0.10%	-0.13%	-0.10%	-0.35%	0.80%
Thies Clima CA-2016-001	-0.33%	-0.38%	-0.88%	1.56%	-0.51%	-0.04%	-0.07%	-0.18%	0.83%

Differences in % (Velocity average = 13m/s)									
	A	B	C	D	E	F	G	H	I
WindSensor CA-2016-002	-0.26%	-0.52%	-0.02%	0.84%	-0.04%	-0.07%	-0.03%	-0.26%	0.37%
Thies Clima CA-2016-001	-0.20%	-0.29%	-0.79%	1.64%	-0.45%	0.00%	-0.07%	-0.18%	0.34%

Per anemometer and per output frequency the results of the calibration of an institute are discarded when the deviation with respect to the estimated reference wind speed was one standard uncertainty of the difference or more. The standard uncertainty of the difference is equal to:

$$\sqrt{1^2 + \left(\frac{1}{\sqrt{N}}\right)^2} \%$$

Where N is the number of non-discarded results per anemometer and output frequency. This step is carried out several times until no more data are discarded. The Measurements are discarded in the order of their deviation, the biggest deviation first.

### 3.5. Definition of Proficiency Test Reference Wind Speed.

For each anemometer and for each output frequency the reference wind speed is defined as the average value of the non-discarded values. The result of this process is shown in the Table 6.

Table 6: Wind speeds for each laboratory, proficiency test reference wind speed and uncertainty of the difference.

Calculated Wind speeds approx. 7 m/s											16ac01 Reference wind speed	Number of institutes	Uncertainty of the difference
	A	B	C	D	E	F	G	H	I				
WindSensor CA-2016-002	6.985	6.940	7.007	7.039	6.985	6.982	6.985	6.964	⊗		6.986	8	1.061%
Thies Clima CA-2016-001	6.960	6.962	6.928	⊗	6.955	6.992	6.994	6.989	⊗		6.969	7	1.069%

  

Calculated Wind speeds approx. 10 m/s											16ac01 Reference wind speed	Number of institutes	Uncertainty of the difference
	A	B	C	D	E	F	G	H	I				
WindSensor CA-2016-002	9.976	9.937	10.002	10.074	9.990	9.987	9.990	9.965	10.080		10.000	9	1.054%
Thies Clima CA-2016-001	9.967	9.962	9.913	⊗	9.949	9.996	9.993	9.983	10.083		9.981	8	1.061%

  

Calculated Wind speeds approx. 13 m/s											16ac01 Reference wind speed	Number of institutes	Uncertainty of the difference
	A	B	C	D	E	F	G	H	I				
WindSensor CA-2016-002	12.966	12.933	12.997	13.109	12.995	12.991	12.996	12.967	13.048		13.000	9	1.054%
Thies Clima CA-2016-001	12.974	12.963	12.898	⊗	12.943	13.000	12.992	12.977	13.044		12.974	8	1.061%

The wind speed deviations are now recalculated using the 16ac01 reference wind speeds.

Table 7: Wind speed deviation to reference wind speed expressed as a percentage.

Differences to reference wind speed (Velocity reference ≈ 7m/s)										
	A	B	C	D	E	F	G	H	I	
WindSensor CA-2016-002	-0.01%	-0.65%	0.29%	0.76%	-0.01%	-0.05%	-0.02%	-0.31%	1.80%	
Thies Clima CA-2016-001	-0.12%	-0.10%	-0.59%	1.86%	-0.19%	0.34%	0.37%	0.29%	2.21%	

  

Differences to reference wind speed (Velocity reference ≈ 10m/s)										
	A	B	C	D	E	F	G	H	I	
WindSensor CA-2016-002	-0.24%	-0.63%	0.02%	0.74%	-0.10%	-0.13%	-0.10%	-0.35%	0.80%	
Thies Clima CA-2016-001	-0.14%	-0.18%	-0.68%	1.76%	-0.32%	0.15%	0.12%	0.02%	1.03%	

  

Differences to reference wind speed (Velocity reference ≈ 13m/s)										
	A	B	C	D	E	F	G	H	I	
WindSensor CA-2016-002	-0.26%	-0.52%	-0.02%	0.84%	-0.04%	-0.07%	-0.03%	-0.26%	0.37%	
Thies Clima CA-2016-001	-0.20%	-0.29%	-0.79%	1.64%	-0.45%	0.00%	-0.07%	-0.18%	0.34%	

### 3.6. Calculation of the Compliance Factor for each laboratory.

At each approximate wind speed (7, 10 and 13 m/s) the difference obtained from each institute for both anemometers result in a series of values with an averaged value and a standard deviation. Both values should be close to zero. The sum of the absolute value of the average and the standard deviation ( $|AV| + stdev$ ) is used as a quantity that characterises the compliance of the calibration institute with the MEASNET-reference-wind speeds. ( $stdev$  = standard deviation of the population).

The values ( $|AV| + stdev$ ) are averaged for the approximate wind speeds (7, 10 and 13 m/s). The institutes with an average value of 1% or less comply with the 16ac01 proficiency test requirement for anemometer calibration.

Table 8: Compliance factors for the 'primary' results provided by all the laboratories.

Compliance factors per wind speed and averaged										
	approx wind speed	A	B	C	D	E	F	G	H	I
$ avg  + stdev$	7 m/s	0.12%	0.65%	0.59%	1.86%	0.19%	0.34%	0.37%	0.31%	2.21%
$ avg  + stdev$	10 m/s	0.24%	0.63%	0.68%	1.76%	0.32%	0.15%	0.12%	0.35%	1.03%
$ avg  + stdev$	13 m/s	0.26%	0.52%	0.59%	1.85%	0.24%	0.20%	0.14%	0.26%	0.54%
$ avg  + stdev$	averaged	<b>0.21%</b>	<b>0.60%</b>	<b>0.62%</b>	<b>1.82%</b>	<b>0.25%</b>	<b>0.23%</b>	<b>0.21%</b>	<b>0.31%</b>	<b>1.26%</b>

## 4. Clarification Sheets

During the development of this Proficiency Test no clarification sheets have been issued. The Measnet procedure for anemometer calibration has been used as a guideline for the evaluation of the data sent by the institutions and as a guide to establish the Pass / Fail criteria.

The use of such document was agreed in a meeting held in Aarhus in February 2016.

## 5. Performance of the IECRE Laboratories

The laboratories that belong to the IECRE system and have participated in the proficiency test are:

- Deutsche WindGuard Wind Tunnel Services GmbH
- WIND-consult GmbH
- SOH Wind Engineering LLC
- Svend Ole Hansen ApS
- Instituto Universitario "Ignacio Da Riva" IDR/UPM

In total 11 wind tunnels have been used from all the institutions belonging to IECRE.

Svend Ole Hansen participated with the consideration of 'secondary' laboratory of SOH Wind Engineering LLC. This only means that its values have not been taken into account to create the proficiency test wind speed.

### 5.1. Compliance Factor.

The compliance factor, as defined in the Measnet Anemometer calibration procedure is the performance indicator selected for this proficiency test. A factor equal to 1% or below is considered as a pass value, while a factor above 1% is considered a fail value.

Compliance factors for the IECRE wind tunnels ranged from 0.21% to 0.60%. Therefore all the IECRE participant laboratories have passed the proficiency test.

Table 9: Compliance factor for the wind tunnels under IECRE system.

<b>Compliance factors per wind speed and averaged. IECRE Laboratories.</b>											
	approx wind speed	A	B	C	D	E	F	G	H	I	J
<b> avg  + stdev</b>	7 m/s	0.37%	0.34%	0.31%	0.30%	0.34%	0.47%	0.50%	0.41%	0.62%	0.65%
<b> avg  + stdev</b>	10 m/s	0.12%	0.15%	0.35%	0.38%	0.30%	0.44%	0.38%	0.45%	0.63%	0.63%
<b> avg  + stdev</b>	13 m/s	0.14%	0.20%	0.26%	0.31%	0.43%	0.32%	0.46%	0.61%	0.53%	0.52%
<b> avg  + stdev</b>	averaged	<b>0.21%</b>	<b>0.23%</b>	<b>0.31%</b>	<b>0.33%</b>	<b>0.35%</b>	<b>0.41%</b>	<b>0.45%</b>	<b>0.49%</b>	<b>0.59%</b>	<b>0.60%</b>

Note: The letters corresponding to each wind tunnel DO NOT correspond to the letter assignment applied in the chapter 3 of this report.

## 5.2. Deviation from proficiency test reference speeds.

The mean deviation of the results is 0.29% at 7 m/s, 0.26% at 10 m/s and 0.25% at 13 m/s. There are not significant differences in the mean deviation between the two anemometers tested.

The minimum deviation among the IECRE members was 0.02%, while the maximum deviation was 0.65%. Although there have been found differences in the recalibration of the Thies anemometer, the results do not show larger deviations for this anemometer than for the Windsensor.

Table 10: Deviation from reference wind speeds for the wind tunnels under IECRE system.

Reference speed $\approx$ 7m/s										
	A	B	C	D	E	F	G	H	I	J
WindSensor	-0.02%	-0.05%	-0.31%	-0.30%	-0.17%	-0.47%	-0.04%	-0.15%	-0.62%	-0.65%
Thies Clima	0.37%	0.34%	0.29%	-0.18%	0.34%	-0.29%	0.50%	0.41%	-0.16%	-0.10%

Reference speed $\approx$ 10m/s										
	A	B	C	D	E	F	G	H	I	J
WindSensor	-0.10%	-0.13%	-0.35%	-0.38%	-0.03%	-0.44%	-0.01%	-0.04%	-0.63%	-0.63%
Thies Clima	0.12%	0.15%	0.02%	-0.25%	0.30%	-0.38%	0.38%	0.45%	-0.29%	-0.18%

Reference speed $\approx$ 13m/s										
	A	B	C	D	E	F	G	H	I	J
WindSensor	-0.03%	-0.07%	-0.26%	-0.31%	0.16%	-0.32%	0.11%	0.13%	-0.53%	-0.52%
Thies Clima	0.14%	0.20%	0.02%	-0.14%	0.43%	-0.28%	0.46%	0.61%	-0.21%	-0.08%

In terms of absolute values this is translated into the following summary results:

Anemometer	7 m/s		10 m/s		13 m/s	
	Standard deviation [m/s]	Maximum deviation [m/s]	Standard deviation [m/s]	Maximum deviation [m/s]	Standard deviation [m/s]	Maximum deviation [m/s]
WindSensor	0.016	0.06	0.023	0.06	0.032	0.07
Thies Clima	0.020	0.05	0.028	0.06	0.038	0.06