

CALIBRATION REPORT OF LIDAR UNIT "WLS7-436"

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TABLE OF SYMBOLS

α	Shear factor	[-]
v	Wind speed	[m/s]
z	Height of the sensor	[m]
TI	Turbulence intensity	[-]
σ_v	Standard deviation of the wind speed	[m/s]
Т	Air temperature	[K]
RH	Relative humidity	[%]
k	Class number of the anemometer	[-]
Kp	Coverage factor	[-]
Ui	Wind speed in bin i	[m/s]
Ν	Number of data set by bin	[-]

DEFINITIONS

Furbulence intensity	$TI = \frac{\sigma_v}{v}$	(1)
----------------------	---------------------------	-----

Shear factor
$$\alpha = \frac{\ln(\frac{v_1}{v_2})}{\ln(\frac{z_1}{z_2})}$$
(2)

Uncertainty contribution from
anemometer behaviour
$$U_{FS\,2,i} = (0.05 \, m/_S + \, 0.005 \, \cdot \, U_i) \cdot \frac{k}{\sqrt{3}}$$
 (3)



1. INTRODUCTION

Following an order of Massachusetts Clean Energy Center a calibration of a LiDAR of the type WindCube V2 by Leosphere (WLS7-436) against a met mast has been performed at a test site in the US.

In this report the measurement results of the LiDAR device are compared to those from calibrated cup anemometers mounted on a met mast. The aim of this comparative assessment is to convey traceability to international standards of this particular LiDAR unit. The evaluation process is based on the IEC 61400-12-1 Ed. 2 Annex L [2]. This standard describes the calibration procedure of remote sensing devices in the frame of power curve measurements on wind turbines. However, this approach generally also applies in the field of wind resource assessment, under the recommendations of MEASNET [4].

The data of the LiDAR measurement (130 m, 125 m, 95 m and 60 m) have been compared with the measured met mast data at 4 different heights (130 m, 125 m, 94 m and 58 m) during a period of 36 days (2019.08.20 – 2019.09.25) for wind speed bins between 4 - 16 m/s and for the wind direction sector $67 - 354^{\circ}$. In addition, measurement results of the met mast and LiDAR unit have been compared in terms of turbulence intensity, wind direction and wind shear.

UL was not involved in the installation of the instruments on the mast but has gathered all relevant information. However, UL was responsible for the installation of the LiDAR unit close to the mast.

It is ensured that the results presented in this report have been measured in an unbiased manner, following the best practices and to the best knowledge of the participating persons.



2. MEASUREMENT SITE

2.1 Description

The test site is located in the state of Texas in the US. The LiDAR unit was located in a distance of about 44 m South-West from the met mast. The altitude of the LiDAR unit was approximately 1100 m above sea level. The mast and LiDAR unit are located at the edge of an open field. The further vicinity of the test site remains flat and consists of open fields and woods.

As far as obstacles are concerned, a turbine is located approximately 300m NNE of tower and a 80m NRG tilt up tower at approximately 500m N of the tower.

The coordinates of the reference mast and the LiDAR are given in Tab. 2.1 Coordinates of the LiDAR and the reference mast (Geographic [deg,min,sec], WGS84).

These coordinates were measured by UL within the accuracy of the GPS measuring device.

Location	Coordinates			
Location	West	North		
LiDAR	101°47'30.36"	34°57'52.44"		
Reference Mast	101°47'29.66"	34°57'53.75"		

Tab. 2.1 Coordinates of the LiDAR and the reference mast (Geographic [deg,min,sec], WGS84)

The test site is suitable for RSD calibration. It is considered as flat terrain according to IEC 61400-12-1 Ed.2 [2]. Topographic data was acquired from the publicly available Shuttle Radar Topography Mission (SRTM) [8]. The site topographical variations and requirements are summarized in the following table.

Tab. 2.2 Topographical conditions at the test site. L: defined as 250 m. Measurement sector considered as full 360°.

Distance	Sector	Allowed maximum slope	Observed maximum slope	Allowed maximum terrain variation from plane	Observed maximum terrain variation from plane	Remark
< 2L	360 degrees	< 3 %	0.9 %	< 16.7 m	3.6 m	pass
≥ 2L and < 4L	Measurement sector	< 5 %	0.6 %	< 33.3 m	6 m	pass
≥ 2L and < 4L	Outside measurement sector	< 10 %	0.7 %	Not applicable	Not applicable	pass
≥ 4L and < 8L	Measurement sector	< 10 %	0.5 %	< 50.0 m	8.6 m	pass
≥ 8L and < 16L	Measurement sector	< 10 %	1.4 %	Not applicable	Not applicable	pass

The maximum slope observed within a range of 500 m (2 L) from the met mast is 0.9%.

The maximum terrain variation from plane within a range of 1 km (4 L) from the met mast is 6 m.

There is a remarkable magnetic declination present at the site: $6.04^{\circ}E \pm 0.34^{\circ}$ changing by $0.10^{\circ}W$ per year.



2.2 Overview



Fig. 2.1 The online resource "Google Earth" provides a good impression of the location [7].



Fig. 2.2 Close-up map of the mast and LiDAR positions.



2.3 Panoramic view of the test site



Fig. 2.3 View towards north.



Fig. 2.5 View towards east.



Fig. 2.4 View towards northeast.



Fig. 2.6 View towards southeast.



Fig. 2.7 View towards south.



Fig. 2.8 View towards southwest.





Fig. 2.9 View towards west.



Fig. 2.10 View towards northwest.



2.4 Determination of the measurement sector

Around the reference mast and the LiDAR, a wind turbine is located which was considered for the determination of the measurement sector.

				•			
Object	X1	Y ²	D ³	Distance to object	Direction from object	Wake	
	[m]	[m]	[m]	[D]	[degrees]	[degrees] [degrees	
		Re	eferenc	ce mast distu	rbed		
WT 1 (Gold wind 3S)	154	261	140	2.17	29	354	67
	Met m	nast un	disturb	ed		67	354
			RS	D disturbed			
WT 1 (Gold wind 3S)	154	261	140	2.48	28	356	64
	LiDA	R und	isturbe	d		64	356
Final Measuren	nent sec	tor ac	cording	to IEC 61400	-12-1 0	67	354

Tab. 2.3 Measurement sector for power curve measurements according to the IEC 61400-12-1 0. The reference mast has been used as a reference (x=0; y=0) in the x;y coordinates.

3. WIND MEASUREMENT

A complete overview of the measuring equipment of the met mast including serial numbers and calibration values is given in Tab. 10.1.

3.1 Description of the met mast

The meteorological mast consists of a Lattice Triangular construction. It has been erected at an altitude of about 1100 m above sea level. The measurement mast is still in use.

The mast layout presents some deviations with respect to IEC 61400-12-1 Ed. 2 [2]. The top anemometer is attached above one corner of the triangular mast; therefore, it should be mounted at a height of at least 11 times the mast section above the mast, this was not respected in this mast layout. Furthermore, the exact orientation of the lightning catcher with respect to the top anemometer could not be fully verified in the documentation. The effect of the lighting catcher however is most likely filtered out by the turbine wake filter presented in section 2.4. In addition, the mast disturbance filter on section 4.4 was also applied to the top anemometer since the top anemometer.

The measured data are recorded by a data logger of type Campbell Scientific CR1000X/2438 with a sampling rate of 1 Hz. The time zone of the logger is set to UTC-6.

The orientation of the booms was measured by UL with a GPS during the site inspection and has been verified.

A visual check of the mast has been performed during the site inspection and the condition of the measurement mast was good.

Only the sensors that were used for the calibration evaluations have been considered here. A complete overview of the sensors mounted on the mast can be found in Fig. 3.1.



¹ Coordinates in east direction (seen from the measured turbine)

² Coordinates in north direction (seen from the measured turbine)

³ Rotor diameter of the WT resp. equivalent rotor diameter of obstacle according to IEC



Fig. 3.1 Sketch of the met mast and its dimensions. Not to scale.



3.1.1 Wind speed

The measurement of wind speed was performed at 4 heights.

At the top of the tower, at 130 m, one cup anemometer of type Thies Clima (v1) have been mounted on an L-shaped boom pointing towards 0° .

A second anemometer (v2) of type Thies Clima was mounted at 125 m on an L-shaped boom pointing towards 294°.

A third anemometer (v3) of type Thies Clima was mounted at 94 m on an L-shaped boom pointing towards 294°.

A fourth anemometer (v4) of type Thies Clima was mounted at 58 m on an L-shaped boom pointing towards 294°.

All the anemometers are classified following IEC 61400-12-1 Ed. 2 [2], Annex I [2] as 0.9A or 1.8A class sensors [6].

All anemometers have been calibrated by the client in a wind tunnel (MEASNET [5], DAkkS/DKD accreditation) before the wind measurement period. The respective calibration certificates are given in the appendices (see section 10.2).

3.1.2 Wind direction

The main wind direction (Dir₁) was measured at a height of 125 m on the met mast with a wind vane of type Thies Clima, mounted on an L-shaped boom. This wind vane is orientated towards 112° and is used as a reference for direction filtering for the calibration evaluations.

3.1.3 Air temperature, relative humidity and air pressure sensors

The temperature was measured at a height of 121 m and the air pressure sensor was measured at a height of 121 m.



3.2 Photo documentation of met mast



Fig. 3.2 Top section. Top mounted anemometer Thies Clima on top boom at 130 m. Anemometer Thies Clima on L-shaped boom at 125 m and wind vane Thies Clima mounted on an L-shaped boom at 125 m. Anemometer Young on L-shaped boom at 122 m and wind vane Thies Clima mounted on an L-shaped boom at 122 m and wind vane Thies Clima mounted on an L-shaped boom at 122 m and wind vane Thies Clima mounted on an L-shaped boom at 122 m and wind vane Thies Clima mounted on an L-shaped boom at 125 m.



Fig. 3.3 Anemometer Thies Clima on L-shaped boom at 94 m and wind vane Thies on an L-shaped boom at 94 m.





Fig. 3.4 Anemometer Thies Clima on L-shaped boom at 58 m and wind vane Thies on an L-shaped boom at 58 m.





Fig. 3.5 Complete mast overview.



3.3 Description of LiDAR unit

The LiDAR device is of type WindCube V2 by Leosphere. The unit ID is "WLS7-436". The unit was located at an elevation of 1100 m above sea level. The measuring range is 40-200 m. At each height measurements of horizontal and vertical wind speed as well as wind direction are performed. For each time step and measuring height a signal quality is supplied in addition.

LiDAR data was synchronized to UTC+0.

The measurement period of the LiDAR device was 2019.08.20 - 2019.09.25 (36 days).

The measurement data are supplied as 10-min statistics values.

According to the information received from the manufacturer, there is no indication of a technical problem or fixed echoes.

3.4 Configuration of the LiDAR

			-								
HeaderSize=40											
Version=2.1.9											
ID System=WLS7-	436										
ID Client=MassCE	C										
Location=MVCO A	SIT										
GPS Location=Lat:	34.964570)N, Long	101.7917;	760W							
Comments=Lense	height is 1	m abov	e agl;								
FCR Option=OFF											
timezone=UIC+0											
Windcube Paramet	ers (intern	al use o	nlv)								
*****			y/								
Sampling Frequence	cy (Hz)=25	000000	0.000								
Ref Frequency (Hz)=6780000	00.000									
Pulses / Line of Sig	ht=20000										
Samples / Pulse=1	024										
Reflected Pulse Sta	art=61										
Reflected Pulse En	Id=135										
Ref pulse samples	nb=1										
Nb High Pass Filter	r Points=5										
FFT Window Width	=50	000									
Laser Diode Curre	nt (mA)=1	900									
LUS=	٥١_00										
Init Drive Position (-)=90										
Pulse Repetition R	ate (HZ)=3		0								
Pulse Duration (s)=		1/5									
May algor Delay Time	=0.000000	JU20									
Vavelengin (nm)-	1043.000										
DirectionOffect (°)-	000										
DirectionOnset () – 2 Poclimation	50.000										
PitchAngle (°)=0.20	00										
RollAngle (°)= 0.20)										
CNRThreshold=-23	3 000										
VrThreshold (m/s)=	NaN										
SigmaFregThresho	old (m/s)=N	laN									
WiperCNRThresho	ld=-19.000)									
WiperAltitude (m)=	100										
WiperDuration (ms)=5000										
Altitudes (m)=	49	59	79	94	99	124	129	139	159	179	199



3.5 Photo documentation of LiDAR unit



Fig. 3.6 LiDAR in its final position.



4. INPUT DATA PREPARATION

4.1 Initial data sets

The data set of the met mast and the LiDAR were provided to UL from the client. The LiDAR data were available in the ".sta" format. The met mast data were provided to UL in their correct physical quantity. The correct application of the calibration values and wind direction offsets was checked to prove consistency by UL.

The measurement period for this calibration is 2019.08.20 - 2019.09.25 (UTC-6).

The availability of the met mast data set amounts to 100% (5293 out of 5293 possible data samples) and the availability of the LiDAR data set amounts to 97.27% (5149 out of 5293 possible data samples).

The availability of the combined met mast and LiDAR data set amounts to 97.27% (5149 out of 5293 possible data samples).

For the calibration evaluation a filtering of the data set is necessary in order to exclude influences that affect the measurement of the met mast's sensors and the measurement of the LiDAR unit. The discussed filter criteria are applied to the original data set. The filtering procedure is performed for each evaluated measuring height separately. On the resulting data set a further visual inspection is performed. The following filters have been applied:

4.2 Signal quality

The LiDAR unit WindCube V2 by Leosphere determines for each 10-min mean value a signal quality value. The quality values relates to the signal to noise ratio detected by the LiDAR and lie generally in the range between 0 - 100. For the calibration evaluation a minimum signal to noise ratio of 80 is recommended by UL. This value has been determined from the user manual of the LiDAR.

4.3 Wind speed

For all evaluations, wind speed has been filtered between 4 and 16 m/s as requested by the IEC 61400-12-1 Ed. 2 Annex L [2]. The wind speed signal recorded at the met tower has been used as a reference. Subsets of the data base have been filtered for studying the relations of wind direction, wind shear and turbulence intensity.

4.4 Wind direction

Wind direction filters have to free the meteorological mast and RSD from wakes from neighbouring wind turbines and other obstacles. Therefore, a wind direction filter has been applied and the resulting measurement sector (see section 2.4) is from 67° to 354°.

Additional wind direction filters in order to avoid any disturbance effects from the met mast structure on the reference cup anemometers should be applied. A standard sector of +/- 45° away from the mast should be excluded from anemometer data. For the top anemometer at height 130 m, the excluded measurement sector is [$335^{\circ}-65^{\circ}$] since the lightening catcher is oriented at 20°. It is to be noted that the orientation for the lightening catcher could not be fully verified with the available documentation as explained in section 3.1.

For the side boom mounted anemometers, the excluded measurement sector is [69°-159°]. The evaluated anemometers at height 125 m, 94 and 58 m are mounted on horizontal booms pointing towards 294°, the remaining measurement sector is from **159° to 335°**. This approach is conservative with the mast disturbance effects observed, see below.

The diagram in Fig 4.2 shows the ratio V_{Mast1}/V_{Mast2} over all directions. It is expected to show a spike around 114° in the wind speed ratio as an indication of the mast wake around this direction. Another spike is expected around 20° to denote the lightening catcher effect on the top anemometer. The latter is not clearly detectable in the diagram as the corresponding sector coincides with the one affected by the turbine's wake.





Fig. 4.2 Wind speed ratio v_{Mast1}/v_{Mast2} over wind direction measurement dir₁. The impact shown is a combination of mast effects.

4.5 Specific filters

For the subset of the turbulence intensity related evaluations, the data base has been filtered as to keep the values for turbulence values between **0.03 and 0.24** as recommended by [2] in table L3. The TI filter is applied only for the evaluation presented in Section 6.2.

For the wind direction evaluation, an additional filtering has been applied. To avoid statistical artefacts caused by angles close to north, reference wind direction between **352.5° and 7.5°** have been excluded as recommended by [3]. The northing filter is applied only for the evaluation presented in Section 6.3.

For wind shear evaluation, the evaluated subset has been filtered as to keep the values for wind shear between **-0.4 and 0.8** as recommended by [2] in table L3. The shear filter is applied only for the evaluation presented in §6.4.

All the filters described previously in 4.2, 4.3, 4.4 and 4.5 are applied to all data, for each bin at every height. The specific filters are additional filters which apply respectively to turbulence intensity, wind direction and wind shear.



4.6 Filtering statistics

The original data set consists of 5149 data samples.

4.6.1 General filters

The table below presents the amount of data samples excluded from the original data set by the different filters. They are applied to all evaluations. A single time step could be flagged by several filters, the union of this filtering is excluded in the final dataset.

Evaluated	Wind s filte	peed r	Wind dir filte	ection er	Signal of filte	quality er	Icing filter			
neight	Number %		Number % Num		Number	%	Number	%	Number	%
130 m	479	9.3	1512	29.36	182	3.53	0	0.00		
125 m	464	9.01	1512	29.36	174	3.38	0	0.00		
94 m	457	8.88	1512	29.36	118	2.29	0	0.00		
58 m	478	9.28	1512	29.36	251	4.87	0	0.00		

Tab. 4.1 Filter statistics for additional filters applied for wind speed evaluations.

4.6.2 Specific filter for turbulence intensity evaluation

The table below presents the amount of data samples excluded from the original data set by filtering turbulence intensity between 0.03 and 0.24.

Tab. 4.2 Filter statistics for additional filters applied for turbulence intensity evaluations.

Evaluated height	Turbulence intensity filter			
	Number	%		
130 m	1492	28.98		
125 m	1455	28.26		
94 m	1282	24.9		
58 m	1070	20.78		

4.6.3 Specific filter for wind direction evaluation

The table below presents the amount of data samples excluded from the original data set by filtering wind direction over North between 352.5 and 7.5.

Tab. 4.3 Filter statistics for additional filters applied for wind direction evaluations.

Evaluated height	Wind direction filter over North			
	Number	%		
130 m	72	1.4		
125 m	72	1.4		
94 m	72	1.4		
58 m	72	1.4		

4.6.4 Specific filter for wind shear evaluation

The table below presents the amount of data samples excluded from the original data set by filtering wind shear exponent between -0.4 and 0.8 as well as filtering RSD measurements for low signal quality.

Evaluated height	Wind sl filte	near r	Quality filter		
	Number	%	Number	%	
125 m 58 m	106	2.06	251	4.87	



5. UNCERTAINTY CALCULATION

The main output of a RSD calibration report as described by [2] is to evaluate the uncertainty resulting from the RSD performance verification test. One should take this uncertainty into account while using the RSD data as primary input for a power curve calibration as requested by [2] or for a bankable energy yield assessment as recommended by [4].

The wind speed measurement uncertainty is calculated for every evaluated height. The considered uncertainty sources are the following [2]:

- The standard uncertainty of the reference sensor (**v_Cup uncertainty**) with the following components (calculated with formula (3), page 8)
 - Calibration uncertainty at $k_p=1$: 0.05 m/s
 - o Class number k of anemometer: Class A 0.9
- The uncertainty due to the mounting effects: 1.2% (top mounted, hub height anemometer), 1.5% (all other cup anemometers evaluated in this report were side boom mounted).
- The wind speed data acquisition system uncertainty: 0.1%
- The standard uncertainty of calibrations between different laboratories: 0.4%
- The mean deviation of the RSD measurements and the reference sensor (**Mean deviation**)
- The standard uncertainty of the measurement of the RSD ($\frac{V_{RSD std}}{\sqrt{N}}$, N representing the number of data per bin)
- The uncertainty of the RSD due to mounting effects has been assumed with 0.1 % in wind speed (**Mounting uncertainty RSD**)
- The uncertainty of the RSD due to non-homogenous flow within the measurement volume has been assumed to be 0 % in wind speed since the terrain is flat and simple.
- The uncertainty due to the distance between the RSD and the reference sensor calculated as 1 % times the separation distance divided by the measurement height. These uncertainties are 0.33% for 130 m, 0.35% for 125 m, 0.46% for 94 m and 0.75% for 58 m.

The resulting uncertainty (**v_RSD uncertainty**) is the root of the quadratic summation of the previous sources.

In order to assess its performance, the mean deviations of the RSD measurements against reference measurements shall be compared to the standard uncertainty of the calibration reduced by the mean deviation. This **uncertainty reduced by mean deviation** is the root of the quadratic summation of all uncertainty sources except the **mean deviation**.

It is recommended by [2] to correct the RSD measurements with the derived correction function $V_{cup}(V_{RSD})$ presented in this report if the mean deviation exceeds the uncertainty reduced by mean deviation in at least one bin.



6. RESULTS OF CALIBRATION

6.1 Calibration of horizontal wind speed measurement

6.1.1 Calibration of horizontal wind speed measurement at 130 m

Total number of used data sets:	3315
Average of v _{cup} of all used data sets:	10.005 m/s
Average of v _{RSD} of all used data sets:	10.124 m/s



Fig. 6.1 Scatter plot of horizontal wind speed and deviation at 130 m for the data set prior to binning.



Fig. 6.2 Plot of bin analysis of horizontal wind speed and deviation at 130 m for the complete bins.



Tab. 6.1 Correction functions from bin linear regression for complete bins at 130 m.									
Correction Function	Slope	Offset	R²						
Fit V _{RSD =} V _{cup} * Slope + Offset	0.9836	0.2778	1.0000						
Inverse fit V _{cup} = V _{RSD} * Slope + Offset	1.0167	-0.2820	1.0000						

Tab. 6.1 Correction functions from bin linear regression for complete bins at 130 m.

Tab. 6.2 Bin analysis of horizontal wind speed and uncertainty calculation at 130 m.

v_Mast	v_RSD	N	v_RSD max	v_RSD min	v_RSD std	v_RSD std/sqrt(N)	Mean deviation	v_Cup uncertainty	Mounting uncertainty RSD	v_RSD uncertainty	Uncertainty reduced by mean
											deviation
[m/s]	[m/s]	[-]	[m/s]	[m/s]	[m/s]	[m/s]	[%]	[%]	[%]	[%]	[%]
4.14	4.29	34	4.65	3.88	0.168	0.029	3.63	2.00	0.10	4.21	2.15
4.50	4.66	80	5.19	4.10	0.232	0.026	3.55	1.88	0.10	4.08	2.00
5.02	5.21	101	5.78	4.65	0.227	0.023	3.62	1.79	0.10	4.08	1.88
5.52	5.70	115	6.38	5.14	0.218	0.020	3.33	1.72	0.10	3.79	1.80
6.01	6.22	123	6.73	5.74	0.204	0.018	3.46	1.67	0.10	3.87	1.73
6.50	6.67	128	7.17	6.09	0.200	0.018	2.73	1.62	0.10	3.20	1.68
7.01	7.19	134	7.62	6.70	0.192	0.017	2.57	1.59	0.10	3.05	1.64
7.51	7.67	163	8.34	7.17	0.199	0.016	2.14	1.56	0.10	2.68	1.61
8.00	8.17	175	8.58	7.68	0.185	0.014	2.14	1.53	0.10	2.66	1.58
8.51	8.65	177	9.23	7.94	0.202	0.015	1.63	1.51	0.10	2.26	1.56
9.01	9.16	150	9.56	8.69	0.189	0.015	1.65	1.49	0.10	2.26	1.54
9.51	9.67	176	10.18	9.19	0.189	0.014	1.62	1.47	0.10	2.22	1.52
10.02	10.17	166	10.58	9.64	0.197	0.015	1.42	1.46	0.10	2.07	1.51
10.51	10.63	160	11.15	10.09	0.213	0.017	1.20	1.45	0.10	1.92	1.50
10.99	11.10	170	11.82	10.64	0.204	0.016	0.96	1.44	0.10	1.77	1.49
11.49	11.59	169	11.94	11.13	0.171	0.013	0.84	1.43	0.10	1.69	1.47
12.00	12.08	163	12.52	11.52	0.202	0.016	0.65	1.42	0.10	1.60	1.47
12.51	12.58	164	13.44	11.95	0.210	0.016	0.59	1.41	0.10	1.57	1.46
13.01	13.08	198	13.67	12.53	0.188	0.013	0.50	1.40	0.10	1.53	1.45
13.51	13.57	182	13.92	13.17	0.162	0.012	0.47	1.40	0.10	1.52	1.44
14.00	14.02	135	14.45	13.46	0.185	0.016	0.17	1.39	0.10	1.45	1.44
14.49	14.51	102	14.90	14.05	0.190	0.019	0.19	1.39	0.10	1.45	1.44
14.99	15.00	81	15.42	14.59	0.186	0.021	0.06	1.38	0.10	1.43	1.43
15.51	15.52	46	16.00	15.17	0.184	0.027	0.01	1.38	0.10	1.43	1.43
15.90	15.91	23	16.14	15.65	0.139	0.029	0.04	1.37	0.10	1.43	1.43

6.1.2 Calibration of horizontal wind speed measurement at 125 m



Fig. 6.3 Scatter plot of horizontal wind speed and deviation at 125 m for the data set prior to binning.



Fig. 6.4 Plot of bin analysis of horizontal wind speed and deviation at 125 m for the complete bins.

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Tab. 6.3 Correction functions from bin linear regression for complete bins at 125 m.									
Correction Function	Slope	Offset	R²						
Fit $V_{RSD} = V_{cup} * Slope + Offset$	0.9748	0.3107	0.9999						
Inverse fit V_{cup} = V_{RSD} * Slope + Offset	1.0257	-0.3182	0.9999						

ab. 6.3 Correction functions from bin linear regression for complete bins at 125 m.

Tab. 6.4 Bin analysis of horizontal wind speed and uncertainty calculation at 125 m.

v_Mast	v_RSD	N	v_RSD max	v_RSD min	v_RSD std	v_RSD std/sqrt(N)	Mean deviation	v_Cup uncertainty	Mounting uncertainty	v_RSD uncertainty	Uncertainty reduced by
									RSD		mean deviation
[[[F (-1	F (-1	[[0/]	[0/]	[0/]	[0/]	[0/]
[m/s]	[m/s]	[-]	[m/s]	[m/s]	[m/s]	[m/s]	[%]	[%]	[%]	[%]	[%]
4.14	4.28	44	4.78	3.80	0.192	0.029	3.33	2.19	0.10	4.07	2.33
4.53	4.68	76	5.17	4.22	0.226	0.026	3.40	2.09	0.10	4.05	2.19
5.03	5.19	93	5.81	4.71	0.207	0.021	3.30	2.01	0.10	3.90	2.08
5.51	5.68	117	6.31	5.09	0.222	0.021	3.11	1.94	0.10	3.70	2.01
6.01	6.19	120	6.71	5.67	0.195	0.018	2.96	1.90	0.10	3.55	1.95
6.49	6.64	133	7.50	6.06	0.215	0.019	2.33	1.86	0.10	3.01	1.91
7.01	7.16	136	7.61	6.72	0.184	0.016	2.01	1.82	0.10	2.75	1.87
7.51	7.64	169	8.31	7.15	0.198	0.015	1.83	1.80	0.10	2.60	1.85
8.01	8.14	175	8.51	7.55	0.180	0.014	1.64	1.78	0.10	2.45	1.82
8.50	8.61	176	9.08	8.19	0.185	0.014	1.25	1.76	0.10	2.19	1.80
8.99	9.12	152	9.55	8.66	0.191	0.015	1.39	1.74	0.10	2.26	1.79
9.50	9.60	167	9.96	9.14	0.189	0.015	1.12	1.73	0.10	2.09	1.77
10.01	10.11	172	10.48	9.56	0.193	0.015	0.98	1.71	0.10	2.01	1.76
10.50	10.57	169	11.15	10.07	0.211	0.016	0.63	1.70	0.10	1.86	1.75
11.00	11.04	173	11.57	10.65	0.196	0.015	0.38	1.69	0.10	1.78	1.74
11.50	11.53	176	11.93	11.04	0.175	0.013	0.27	1.69	0.10	1.75	1.73
12.00	12.01	153	12.52	11.61	0.186	0.015	0.05	1.68	0.10	1.72	1.72
12.51	12.51	169	13.38	11.77	0.221	0.017	0.00	1.67	0.10	1.72	1.72
13.00	12.99	185	13.63	12.54	0.192	0.014	-0.08	1.67	0.10	1.71	1.71
13.50	13.47	199	13.89	12.87	0.177	0.013	-0.20	1.66	0.10	1.72	1.70
13.98	13.92	122	14.41	13.49	0.181	0.016	-0.46	1.66	0.10	1.76	1.70
14.48	14.42	110	14.89	14.03	0.176	0.017	-0.39	1.65	0.10	1.74	1.70
14.98	14.91	74	15.29	14.54	0.180	0.021	-0.45	1.65	0.10	1.75	1.69
15.49	15.38	43	15.76	15.07	0.167	0.025	-0.75	1.65	0.10	1.85	1.69
15.89	15.76	28	16.02	15.57	0.125	0.024	-0.79	1.64	0.10	1.86	1.69



6.1.3 Calibration of horizontal wind speed measurement at 94 m



Fig. 6.5 Scatter plot of horizontal wind speed and deviation at 94 m for the data set prior to binning.



Fig. 6.6 Plot of bin analysis of horizontal wind speed and deviation at 94 m for the complete bins.



Tab. 6.5 Correction functions from bin linear regression for complete bins at 94 m.					
Correction Function	Slope	Offset	R²		
Fit $V_{RSD} = V_{cup} * Slope + Offset$	0.9790	0.2918	0.9999		
Inverse fit V_{cup} = V_{RSD} * Slope + Offset	1.0214	-0.2973	0.9999		

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Tab. 6.6 Bin analysis of horizontal wind speed and deviation at 94 m.

v_Mast	v_RSD	N	v_RSD max	v_RSD min	v_RSD std	v_RSD std/sqrt(N)	Mean deviation	v_Cup uncertainty	Mounting uncertainty	v_RSD uncertainty	Uncertainty reduced by
									RSD		mean deviation
[m/s]	[m/s]	[-]	[m/s]	[m/s]	[m/s]	[m/s]	[%]	[%]	[%]	[%]	[%]
4.13	4.26	37	4.73	3.90	0.186	0.031	3.10	2.19	0.10	3.89	2.36
4.50	4.68	77	5.18	4.25	0.206	0.023	3.95	2.09	0.10	4.53	2.20
5.02	5.20	90	5.62	4.70	0.201	0.021	3.58	2.01	0.10	4.16	2.11
5.51	5.68	130	6.03	5.28	0.183	0.016	3.01	1.94	0.10	3.63	2.02
6.02	6.18	145	6.72	5.55	0.201	0.017	2.64	1.90	0.10	3.30	1.97
6.51	6.68	145	7.33	6.24	0.198	0.016	2.57	1.86	0.10	3.21	1.93
7.02	7.15	176	7.58	6.66	0.182	0.014	1.87	1.82	0.10	2.66	1.90
7.51	7.65	183	8.18	7.14	0.208	0.015	1.89	1.80	0.10	2.66	1.87
8.00	8.14	215	8.62	7.59	0.189	0.013	1.83	1.78	0.10	2.60	1.85
8.51	8.65	175	9.09	8.16	0.199	0.015	1.63	1.76	0.10	2.45	1.83
9.02	9.14	178	9.52	8.64	0.175	0.013	1.42	1.74	0.10	2.30	1.81
9.51	9.63	193	10.19	9.24	0.182	0.013	1.25	1.73	0.10	2.19	1.80
10.00	10.11	226	10.51	9.57	0.175	0.012	1.08	1.71	0.10	2.09	1.78
10.50	10.60	221	11.10	10.09	0.189	0.013	0.90	1.70	0.10	1.99	1.77
11.02	11.09	177	11.56	10.69	0.185	0.014	0.64	1.69	0.10	1.88	1.77
11.51	11.58	173	12.20	10.77	0.184	0.014	0.61	1.69	0.10	1.86	1.76
12.01	12.07	196	13.17	11.67	0.187	0.013	0.47	1.68	0.10	1.81	1.75
12.51	12.56	208	12.98	12.18	0.180	0.012	0.42	1.67	0.10	1.79	1.74
13.00	13.04	157	13.51	12.64	0.174	0.014	0.31	1.67	0.10	1.76	1.74
13.48	13.51	117	13.99	13.15	0.166	0.015	0.18	1.66	0.10	1.74	1.73
13.97	13.98	75	14.43	13.60	0.170	0.020	0.11	1.66	0.10	1.73	1.73
14.45	14.41	31	14.70	14.10	0.159	0.029	-0.30	1.65	0.10	1.76	1.73
14.97	14.92	21	15.18	14.59	0.174	0.038	-0.39	1.65	0.10	1.78	1.74
15.48	15.45	7	15.56	15.24	0.098	0.037	-0.21	1.65	0.10	1.74	1.73
15.84	15.71	4	15.80	15.63	0.083	0.042	-0.82	1.64	0.10	1.92	1.73



6.1.4 Calibration of horizontal wind speed measurement at 58 m



Fig. 6.7 Scatter plot of horizontal wind speed and deviation at 58 m for the data set prior to binning.



Fig. 6.8 Plot of bin analysis of horizontal wind speed and deviation at 58 m for the complete bins.



Tab. 6.7 Correction functions from bin linear regression for complete bins at 56 m.				
Correction Function	Slope	Offset	R²	
Fit V _{RSD =} V _{cup} * Slope + Offset	0.9752	0.2632	0.9998	
Inverse fit V_{cup} = V_{RSD} * Slope + Offset	1.0252	-0.2677	0.9998	

Tab. 6.7 Correction functions from bin linear regression for complete bins at 58 m.

Tab. 6.8 Bin analysis of horizontal wind speed and deviation at 58 m. Bins over 15 m/s are incomplete.

v_Mast	v_RSD	N	v_RSD max	v_RSD min	v_RSD std	v_RSD std/sqrt(N)	Mean deviation	v_Cup uncertainty	Mounting uncertainty RSD	v_RSD uncertainty	Uncertainty reduced by mean
											deviation
[m/s]	[m/s]	[-]	[m/s]	[m/s]	[m/s]	[m/s]	[%]	[%]	[%]	[%]	[%]
4.08	4.20	34	4.49	3.92	0.133	0.023	2.87	2.19	0.10	3.73	2.38
4.50	4.61	93	4.98	4.23	0.182	0.019	2.53	2.09	0.10	3.40	2.26
5.01	5.13	116	5.58	4.73	0.201	0.019	2.44	2.01	0.10	3.27	2.18
5.51	5.62	150	6.19	5.17	0.187	0.015	1.94	1.94	0.10	2.87	2.11
5.99	6.11	186	6.75	5.65	0.190	0.014	1.87	1.90	0.10	2.78	2.06
6.52	6.64	179	7.11	6.17	0.183	0.014	1.80	1.86	0.10	2.70	2.02
6.99	7.09	217	7.80	6.62	0.197	0.013	1.43	1.82	0.10	2.45	1.99
7.51	7.60	231	8.18	6.99	0.197	0.013	1.16	1.80	0.10	2.28	1.96
8.00	8.09	260	8.64	7.68	0.182	0.011	1.02	1.78	0.10	2.19	1.94
8.51	8.57	240	8.97	8.22	0.174	0.011	0.74	1.76	0.10	2.06	1.92
9.00	9.06	260	9.74	8.68	0.182	0.011	0.71	1.74	0.10	2.03	1.91
9.50	9.56	275	9.99	9.15	0.168	0.010	0.60	1.73	0.10	1.98	1.89
9.99	10.03	257	10.66	9.56	0.182	0.011	0.35	1.71	0.10	1.91	1.88
10.52	10.53	218	10.99	9.96	0.182	0.012	0.13	1.70	0.10	1.88	1.87
11.01	11.02	210	11.67	10.65	0.189	0.013	0.12	1.69	0.10	1.87	1.86
11.50	11.46	148	11.89	11.08	0.181	0.015	-0.30	1.69	0.10	1.88	1.86
11.99	12.00	103	12.82	11.58	0.221	0.022	0.08	1.68	0.10	1.86	1.85
12.46	12.44	82	13.03	12.01	0.207	0.023	-0.18	1.67	0.10	1.86	1.85
12.91	12.91	24	13.25	12.63	0.161	0.033	-0.06	1.67	0.10	1.86	1.85
13.44	13.44	9	13.65	13.17	0.156	0.052	-0.04	1.66	0.10	1.87	1.87
13.93	13.80	3	13.97	13.70	0.123	0.071	-0.98	1.66	0.10	2.13	1.90
14.45	14.18	4	14.26	14.12	0.051	0.026	-1.85	1.65	0.10	2.61	1.83
15.35	15.31	2	15.44	15.17	0.135	NA	NA	NA	NA	NA	NA



6.2 Calibration of turbulence intensity

6.2.1 Calibration of turbulence intensity at 130 m

Total number of used data sets:	2374
Average turbulence intensity based on v_mast of all used data sets:	0.097
Average turbulence intensity based on v_RSD of all used data sets:	0.125







Fig. 6.10 Plot of bin analysis of turbulence intensity and deviation at 130 m.



6.2.2 Calibration of turbulence intensity at 125 m

Total number of used data sets:	2411
Average turbulence intensity based on v_mast of all used data sets:	0.097
Average turbulence intensity based on v RSD of all used data sets:	0.124



Fig. 6.11 Scatter plot of turbulence intensity and deviation at 125 m.



Fig. 6.12 Plot of bin analysis of turbulence intensity and deviation at 125 m.



6.2.3 Calibration of turbulence intensity at 94 m

Total number of used data sets:	2548
Average turbulence intensity based on v_mast all used data sets:	0.097
Average turbulence intensity based on v RSD all used data sets:	0.117



Fig. 6.13 Scatter plot of turbulence intensity and deviation at 94 m.

Fig. 6.14 Plot of bin analysis of turbulence intensity and deviation at 94 m.

6.2.4 Calibration of turbulence intensity at 58 m

Total number of used data sets:	2687
Average turbulence intensity based on v_mast all used data sets:	0.100
Average turbulence intensity based on v RSD all used data sets:	0.113

Fig. 6.15 Scatter plot of turbulence intensity and deviation at 58 m.

Fig. 6.16 Plot of bin analysis of turbulence intensity and deviation at 58 m.

6.3 Calibration of wind direction measurement

6.3.1 Calibration of wind direction measurement at 125 m

Total number of used data sets:	4535
Average of dir_mast of all used data sets:	180.258 deg
Average of dir RSD of all used data sets:	177.385 dea

Fig. 6.17 Scatter plot of wind direction and deviation at 125 m.

Fig. 6.18 Plot of bin analysis of wind direction and deviation at 125 m.

6.4 Calibration of wind shear

6.4.1 Calibration of wind shear between 125 m and 58 m

Total number of used data sets:	3249
Average shear of v_mast signals of all used data sets:	0.210
Average shear of v RSD signals of all used data sets:	0.220

Fig. 6.19 Scatter plot of wind shear and deviation between 125 m and 58 m.

Fig. 6.20 Plot of bin analysis of wind shear and deviation between 125 m and 58 m.

7. COMPLIANCE WITH THE IEC STANDARD REQUIREMENTS

Criterion	Minimum Standard	Reported Value	Criterion fulfilled
Met mast sensors should be compliant with IEC V2		Thies Clima	YES
	Use same averaging intervals for LIDAR and mast measurements	10min	YES
	Record Avg, Std, extreme values, number of samples in 10 min period		YES
Data acquisition	Synchronization of RSD and mast sensors to within 1% of the averaging interval, test for synchronization once a week	No direct synchronization established	NO
	Wind speed measurements binned into 0,5 m/s and wind direction binned into 5° bins		YES
	Each bin centered between 4 m/s and 16 m/s should have at least 3 pairs of measurements	Some bins are empty or incomplete*	NO
	The amount of acquired data shall cover at least 180 hours	3315 data sets for top evaluation => 552 hours	YES
	Reference Mast and RSD free from wakes based on annex A	Disturbed sectors excluded	YES
	Reference cup anemometer not influenced by icing	No icing detected	YES
Data preparation	Filtering for precipitation should only be undertaken if required by manufacturer	Not required	YES
	Correct mast effects on boom mounted anemometers	Disturbed sectors excluded	YES
Use bin averaging to compare the RSD and Mast measurement	Detailed procedure presented in annex L.3 of the standard		YES
Calculate the total uncertainty of the RSD	Follow recommendations of Annex L.4.2 of the standard		YES

* Due to a lack of high wind speeds during the calibration period, some bins are empty or incomplete. The RSD measurement uncertainty could not be evaluated for these bins. The impact of the effect is larger for the levels closer to the ground. UL believes that the most sensitive wind speed range for wind turbine power production is covered. Furthermore, based on the wind speed measurement principle of the RSD as well as the data available in the sparsely populated bins it is reasonable to assume that a correction function can be applied to the wind speed range up to 16 m/s as well.

8. CONCLUSIONS

UL performed the calibration test of the LiDAR WLS7-436 in flat terrain with an IEC compliant met mast. The evaluation is based on simultaneous measurements ranging from 2019.08.20 to 2019.09.25. The two data bases have been filtered and evaluated following the recommendations in the available version of the IEC 61400-12-1 Ed. 2 Annex L [2].

The correlations of the wind speeds in terms of R^2 are good at all heights ($R^2 > 0.9998$ for the binned results). The RSD measurement uncertainty has been evaluated and is presented in this report binwise for each evaluated height. Various correlation functions between the RSD wind speed and the reference sensors wind speed are also presented for each evaluated height.

The correlation of wind direction measurements is very good (slope = 1.0002, R² = 0.9999). The RSD wind direction is lower than the met mast reported wind direction by a value of 3°. This is probably due to the northing uncertainty for both met mast wind vane and RSD device.

The correlations give good results at all evaluated heights in terms of turbulence intensity. In general, the RSD gives higher binned values (by approximately 0.02) than the reference sensors.

The correlation of calculated wind shear is good (slope = 0.9993, $R^2 = 0.9995$ for binned averages). The RSD wind shear is higher than the met mast wind shear by approximately 0.01.

The criterion for applying a correction to a RSD measurement is given by the available version of the IEC 61400-12-1 Ed. 2 Annex L [2] explained in section 0.

This version of the IEC 61400-12-1 Ed. 2 Annex L [2] recommends to apply a correction function if the bin-averaged deviations exceeds the reduced uncertainty (as defined in section 5 Uncertainty Calculation).

This criterion is reached for 12 bins for height 130 m. The bins are centered between 4 m/s and 9.5 m/s, and have in total 1556 data couple which represents 47% of the data set.

This criterion is reached for 7 bins for height 125 m. The bins are centered between 4 m/s and 7 m/s, and have in total 719 data couple which represents 21% of the data set.

This criterion is reached for 7 bins for height 94 m. The bins are centered between 4 m/s and 7.5 m/s excluding 7m/s , and have in total 807 data couple which represents 24% of the data set.

This criterion is reached for 4 bins for height 58 m. The bins are centered between 4 m/s and 5 m/s, and 14.5 m/s, they have in total 247 data couple which represents 7.5% of the data set.

As the criterion has been reached for several bins at all heights, a correction function can be applied to the data. One is free to decide on the exact form of correction to apply.

Based on the results of the calibration of this RSD, and following the recommendations of the available version of the IEC 61400-12-1 Ed. 2 Annex L [2], the device WLS7-436 can be used with care in a wind measurement campaign in simple terrain provided the measurement campaign begins within one year of this calibration and the same filter settings are applied.

According to IEC 61400-12-1, a calibration shall be considered as valid if the reference anemometer is mounted with \pm 25% of the planned wind turbine hub height. Since the reference anemometer for this calibration is 130 meters, if this test were specifically for a power curve test, this calibration test would be valid for hub heights in the height range 104 m and 173 m.

In case there is major service on the device (software update, speaker/antenna changes, etc.) the test should be repeated before starting a measurement campaign.

9. REFERENCES

- [1] IEC 61400-12-1, First edition 2005-12, Wind turbines part 12-1: Power performance measurements of electricity producing wind turbines. Here focus on the annex F, G and Describing anemometer classification, mounting of sensors.
- [2] IEC 61400-12-1, Ed.2, 2017-03, Wind turbines part 12-1: Power performance measurements of electricity producing wind turbines. Here focus on the annex L.
- [3] IEA Wind, First Edition, January 2013, 15. Ground-based vertically-profiling remote sensing for wind resource assessment.
- [4] MEASNET, "Evaluation of Site-Specific Wind Conditions", Version 1, November 2009.
- [5] MEASNET, "Cup anemometer calibration procedure", Version 1, September 1997.
- [6] ACCUWIND Classification of Five Cup Anemometers According to IEC 61400-12-1, T.F. Pedersen, J.-A. Dahlberg, Peter Busche, Risø-R-1556(EN), May 2006/ Thies ClimaAdvanced Anemometer data sheet.
- [7] Google Earth.
- [8] Shuttle Radar Topography Mission (SRTM) http://srtm.csi.cgiar.org/.

West Texas

Calibration report of LiDAR unit "WLS7-436"

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10. APPENDIX

10.1 Description of the test equipment

Tab. 10.1: Table of test equipment.

Sensor	Туре	Make	Installation Date	Dismantling Date	Range	Resolution	Accuracy	Measuring Height	Calibration
Wind speed I, v1	Cup anemometer Serial No: 12166019	Thies Clima	2018-05-31	Still mounted	0.3 – 75 m/s	0.05 m/s	1%	130.0m	See Sec 10.2
Wind speed II, v2	Cup anemometer Serial No: 07176835	Thies Clima	2018-05-31	Still mounted	0.3 – 75 m/s	0.05 m/s	1%	125.0m	See Sec 10.2
Wind speed III, v3	Cup anemometer Serial No: 0161808	R.M.Young	2018-05-31	Still mounted	0 – 100 m/s	0.05 m/s	1%	122.0m	-
Wind speed IV, v4	Cup anemometer Serial No: 01180032	Thies Clima	2018-05-31	Still mounted	0.3 – 75 m/s	0.05 m/s	1%	94.0m	See Sec 10.2
Wind speed V, v5	Cup anemometer Serial No: 03176369	Thies Clima	2018-05-31	Still mounted	0.3 – 75 m/s	0.05 m/s	1%	58.0m	See Sec 10.2
Wind direction I, dir1	Wind vane Serial No: 06190414	Thies Clima	2019-08-02	Still mounted	0 – 360°	0.35°	±0.75 %	125.0m	See Sec 10.3
Wind direction II, dir2	Wind vane Serial No: 06190413	Thies Clima	2019-08-02	Still mounted	0 – 360°	0.35°	±0.75 %	122.0m	See Calibration certificate in 10.3
Wind direction III, dir3	Wind vane Serial No: 06190412	Thies Clima	2019-08-02	Still mounted	0 – 360°	0.35°	±0.75 %	94.0m	See Sec 10.3
Wind direction III, dir4	Wind vane Serial No: 06190411	Thies Clima	2019-08-02	Still mounted	0 – 360°	0.35°	±0.75 %	58.0m	See Sec 10.3

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Calibration report of LiDAR unit "WLS7-436"

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Air temperature T1	Serial No: 183591	Galltec/Mela KPC1.S/6- ME	2018-05-31	Still mounted	-35 °C+70° C	analogue	±0.2°K	121.0 m	See Sec 10.4
Relative Humidity H1	Serial No: 183591	Galltec/Mela KPC1.S/6- ME	2018-05-31	Still mounted	0100 %	analogue	± % for range 595 % at 1040 °C	121.0 m	See Sec 10.4
Air pressure P1	Serial No: N1720456	Vaisala PTB110	2018-05-31	Still mounted	610 – 1100 mbar	±0.03 hPA	±0.15 hPa	121.0 m	See Sec 10.4
Air temperature T2	Serial No: 176894	Galltec/Mela KPC1.S/6- ME	2018-05-31	Still mounted	-35 °C +70°C	analogue	±0.2°K	10.0 m	See Sec 10.4
Relative Humidity H2	Serial No: 176894	Galltec/Mela KPC1.S/6- ME	2018-05-31	Still mounted	0100%	analogue	± % for range 595 % at 1040 °C	10.0 m	See Sec 10.4
Air pressure P2	Serial No: N1720454	Vaisala PTB110	2018-05-31	Still mounted	610 – 1100 mbar	±0.03 hPA	±0.15 hPa	10.0 m	See Sec 10.4
Data acquisition system	Data logger Serial No.: 2438	CR1000X	2018-06-12	Still mounted	-	-	-	-	See Sec 10.5

10.2 Anemometer calibration protocols

10.2.1 Calibration protocol v₁

		DEUTSCHE	Page 2 / 4 Seite			17101 D-K- 15140-01
Deutsche Wir Wind Tunnel	ndGuard Services GmbH, Varel	WINDGUARD				01/201
accredited by the / a	akkreditiert durch die		Calibration object Kolibriergegenstand	Cup Anemometer		
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as calibration labora	tory in the / als Kalibrierlaborator	rium im		MEASNET: Anemometer cali IEC 61400-12-1: Power performance	bration procedure rmance measurements of electricity	v producin
Deutschen Ka	e elibrierdienst	KD 1710103 D-X-X 15140-01-00 KD 15140-01-00		wind turbines • IEC 61400-12-2: Power perfors based on nacelle anemometry • ISO 3966: Measurement of fl • ISO 16622: Meteorology - So	rmance of electricity producing win uid in closed conduits nic anemometers/thermometers	d turbines
name i senem		01/2017	Place of calibration Ort der Kalibrierung	Windtunnel of Deutsche Wind	Guard WindTunnel Services GmbH,	Varel
Object Gegenstand	Cup Anemometer	This calibration certificate documents the traceability to national standards, which realize	 Test conditions	wind tunnel area	10000 cm ²	
Manufacturer	Thies Clima	the units of measurement according to the International System of Units (SI).	in concerning on great	anemometer frontal area	230 cm ²	
no seno	D-37083 Göttingen	The DAkkS is signatory to the multilateral		diameter of mounting pipe	34 mm	
Type Typ	4.3351.00.000	Accreditation (EA) and of the International		blockage ratio 1)	0.023 [-]	
Serial number	12166019	the mutual recognition of calibration certificates.		software version	7.64	
Fabrikat/Serien-Nr.		The user is obliged to have the object recalibrated at appropriate intervals.		²⁾ Due to the special construction of th	e test section no blockage correction is nece	issary.
Customer Auftraggeber	UL International GmbH - DEWI D-26382 Wilhelmshaven	Dieser Kalibrierschein dokumentlert die Rück- führung auf nationale Normale zur Darstellung der Einheiten in Übereinstimmung mit dem	Ambient conditions	air temperature	18.2 °C ± 0.1 °C	
Order No.	3710001689	Internationalen Einheitensystem (SI).		air pressure	1018.5 hPa ± 0.3 hPa	
Project No.	VT161193	Übereinkommen der European co-operation for		relative air humidity	38.4 % ± 2.0 %	
Projektnummer Number of pages Anzahl der Seiten	4	Accreditation (EA) und der International Laboratory Accreditation Cooperation (ILAC) zur gegenseitigen Anerkennung der Kalibrierscheine. Für die Einhaltung einer angemessenen Frist zur Wildebelung der Kalibrierung in der Der ber	Measurement uncertainty Messunsicherheit	The expanded uncertainty assi multiplying the standard uncer determined in accordance with	gned to the measurement results is tainty by the coverage factor k = 2.	obtained I It has been asurand lie
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10.2.2 Calibration protocol v₂

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Deutsche WindGuard Wind Tunnel Services GmbH, Varel

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10.2.3 Calibration protocol v₄

DEUTSCHE WINDGU	IARD		~	Page 2 / 4 Seite		D-K- 15140-01- 02/201
Deutsche Win Wind Tunnel	ndGuard Services GmbH IECR	E and MEASNET approved test la	boratory	Calibration object	Cup Anemometer	
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Deutschen Ka	librierdienst		310507 р-к-		 ISO 3966:2008 Measurem ISO 16622:2002 Meteorol 	ent of fluid in closed conduits ogy - Sonic anemometers/thermometers
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Object Gegenstand Manufacturer Hersteller	Cup Anemometer Thies Clima D-37083 Göttingen	This calibration certificate docum traceability to national standards, whi the units of measurement accordin International System of Units (SI). The DAKKS is signatory to the m agreements of the European co-ope	ents the ich realize g to the nultilateral ration for	Tesc conditions Messbedingungen	diameter of mounting pipe	230 cm² 34 mm EN 10217 0.023 (-)
Type Typ Serial number Fabrikat/Serien-Nr. Customer Auftrageeber	4.3351.00.000 01180032 UL International GmbH - DEWI	Accreditation (EA) and of the Int Laboratory Accreditation Cooperation the mutual recognition of calibration co The user is obliged to have th recalibrated at appropriate intervals. Dieser Kolibrierschein dokumentiert filterung wit notionet korrende zur O	ernational (ILAC) for ertificates. ne object die Rück- terstellung	Ambient conditio Umgebungsbedingung	software version ¹¹ Due to the special construction o ns air temperature air pressure	7.7 if the test section no blockage correction is necessary, 21.5 °C ± 0.1 °C 995.7 hPa ± 0.3 hPa
Order No. Auftragsnummer Project No. Projektnummer	D-26382 Wilhelmshaven 3710003234 VT180142	Juliung day notionale volumite zur D der Einhelten in Übereinstimmung Internationalen Einheltensystem (SI). Die DAkkS ist Unterzeichner der muh Übereinkommen der European co-ope Accreditation (EA) und der Int Laboratory Accreditation Cooperation	anteung mit dem tilateralen rration for ernotional (ILAC) zur	Measurement un Messunsicherheit	relative air humidity certainty The expanded uncertainty a multiplying the standard un determined in accordance v	36.7 % ± 2.0 % ssigned to the measurement results is obtained I certainty by the coverage factor i=2. It has been it hD Akk5-DK-3. The value of the measurand lif
Number of pages Anashl der Selten Date of Calibration Datum der Kalibrierung	4 01.02.2018	gegenseitigen Anerkennung der Kalibri Für die Einhaltung einer angemessene Wiederhalung der Kalibrierung ist der verantwartlich.	erscheine. n Frist zur Benutzer		within the assigned range of The reference flow speed m (Physikalisch-Technische Bu by using a PTB owned and c Uncertainty 0.2 %, k=2)	f values with a probability of 95%. easurement is traceable to the German NMI ndesanstait) standard for flow speed. It is realize alibrated Laser Doppler Anemometer (Standard
This calibration certificate Accreditation Body and th certificate has been general Dieser Kalibrierschein darf i Genehmigung sowohl der D ohne Unterschrift hoben ke	may not be reproduced other than in fui he issuing laboratory. Calibration certificate ted electronically. nur vollständig und unverändert weiterverbre Deutschen Akkreditierungsstelle als auch des eine Gültigkeit. Dieser Kollbrierschein wurde ele	I except with the permission of both the s without signature are not valid. This cu itet werden. Auszüge oder Änderungen bed uusstellenden Kalibrierlaboratoriums. Kalibrie ktronisch erzeugt.	German alibration Urfen der erscheine	Additional remark Zusätzliche Anmerkung	GS - Pën	
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				Deutsche WindG Wind Tunnel Ser	uard vices GmbH, Vare!	WINDGUAI
nge 3 / 4 rite		181 b 1314140 02/	0507 	Deutsche Wind Wind Tunnel Ser Page 4 / 4 Seite	uaro	18105 D-8- 554001 02/201
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age 3 / 4 vie Calibration result Kolknerogebia Sensor Hz 81.129 123.572	Turinel Speed n/s 3.960 5.890	181 0 15144 02/ Uncertainty n/s 0.050 0.051	0507 +¥- 2018	Deutsche WindG Wind Tunnel Ser Page 4 / 4 Sere Graphical represe Graphical represe G	uaro vices GmbH, Varel station of the result Galibration No: 1810607 rel	18105 04 15140 01 02/201 7; 01180032; 2.2
age 3 / 4 ter Calibration result Kalineregebns Sensor 182 81.139 123.572 165.682	Turini Speed m/s 3.950 5.890 7.880	181 15144 02/ Uncertainty m/s 0.050 0.051	0507 ** 19100 2018	Deutsche WindG Wind Tunnel Ser Page 4 / 4 Seiter Graphical repress Graphical repress Graphical repress 18	uaro vices GmbH, Varel intation of the result des optimizes Calibration No: 181050	22 7; 01180032; 0.1
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2014 Calibration result Calibration result 11.29 11.29 11.3572 165.682 205.957 253.347 259.344 335.072 315.683 275.444 220.589 117.345 117.34	Tunni Speed n/s 3.960 5.880 7.880 9.899 11.518 13.835 15.809 14.805 12.888 10.878 8.869	Uncertainty w/s 0,550 0,550 0,551 0,551 0,551 0,551 0,551 0,551 0,551 0,552 0,652 0,652 0,552 0,552 0,552 0,552 0,552 0,552 0,552 0,552 0,552 0,552 0,552 0,552 0,552 0,552 0,552 0,555	0507 	Page 4 / 4 Page 4 / 4 Graphical repress Graphical repress Graphica	uaro vices GmbH, Varel station of the result de optimizer Calibration No: 181060	7; 01160032; 7; 01160032; 0.1 0.1 0.1 0.1 0.1
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age 3 / 4 calibration result (districtorpolis)	Tunnel Speed n/s 3.900 7.880 7.880 7.880 9.899 11.518 13.855 15.609 14.606 12.888 10.878 14.606 12.888 10.878 10.878 14.606 12.888 10.878 10.914 14.006 12.888 10.914 14.006 12.888 10.914 14.006 12.888 10.914 14.006 12.888 10.914 14.006 12.888 10.914 14.006 12.888 10.914 14.006 12.888 10.914 14.006 12.888 10.914 14.006 12.888 10.914 14.006 12.888 10.914 14.006 12.888 10.914 14.006 12.888 10.914 14.006 12.889 11.518 13.885 14.806 14.906 14.9	Uncertainty m/s Uncertainty m/s 0.050 0.051 0.051 0.051 0.052 0.055 0	0507 K- 2018	Deutsche Wind Wind Tunnel Ser Page 4/4 Graphical represe Orginale Contribution 10 10 10 10 10 10 10 10 10 10 10 10 10	station of the result des openings: Calibration No: 181060 des openings: des openings:	7; 01180032; 7; 01180032; 280 300 350 400 280 300 350 400
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age 3 / 4 Calibration result Kollineregebns 5ensor 182 18.139 12.3572 165.683 20.967 23.347 29.344 125.347 29.349 187.363 275.443 101.652 101.652 Xatistical analysis	Turnet Speed m/s 3 990 5 890 7 880 9 989 9 11 518 13 835 13 835 13 835 14 846 12 888 6 394 4 305 5 Jope 0.040 Offset 0.234 Standard error (V) 0.011 Correlation corf() 0.019 Correlation corf() 0.019 Corf() 0.019 Cor	181 D Uncertainty m/s 0.050 0.051 0.051 0.052 0.052 0.052 0.052 0.052 0.051 0.052 0.052 0.051 0.052 0.052 0.051 0.052 0.051 0.052 0.051 0.052 0.051 0.052 0.051 0.052 0.052 0.051 0.052 0.051 0.052 0.052 0.051 0.052 0.051 0.050 //w.st0.015 m/s im/s 1035 1047 1058 1059 1059	0507 -*- 2018	Page 4 / 4 Page 4 / 4 Serr Graphical represent Graphical represent	suizes GmbH, Varel station of the result Galibration No: 181050 Galibration No: 181050 Source and Source an	280 300 350 450.2 WinDourse
age 3/4 fe Sensor 11,2357 165682 233.347 254.347 255.347	Turnet Speed m/h 3.500 5.800 7.880 9.859 13.513 13.513 13.835 13.835 13.836 6.934 4.916 Slope 0.044 Offset 0.234 Standard error (Y) 0.011 Correlation coefficient 0.959 The calibrated sensor complies w demanded linearity of MEASNET	181 0 1314 0 0.050 0.051 0.051 0.052 0.052 0.052 0.052 0.052 0.052 0.052 0.053 0.052 0.052 0.053 0.051 0.052 0.053 0.053 0.051 0.052 0.053 0.053 0.051 0.052 0.053 0.050 //example 14 m/s 20015 m/s 3m/s 99 10 ft g.g.	0507 	Page 4 / 4 Graphical representations Page 4 / 4 Graphical representations Controlled on the mean page 1 Calculated out Photo of the mean page 1 Of 02 2010 Cer No.	surres GmbH, Varel stration of the result Georgeneous	280 300 350 400 2 mituate
nge 3 / 4 te 2.allbration result 0.00000000000000000000000000000000000	Turnel Speed n/s 3.960 5.800 7.880 9.899 11.513 13.835 13.835 14.806 12.888 10.873 8.668 6.934 4.936 Standard error (Y) Correlation coefficient Correlation coefficient The calibrated sensor compiles w demanded linearity of MEASNET	181 05544 02/ 0600 0601 0602 0603 0604 0605 0705 <	0507 *** 2018 2018	Page 4 / 4 Series Page 4 / 4 Graphical represent Graphical represent	station of the result des Expensions des Expensions	18105 18105 02/201 02/201 0

Massachusetts Clean Energy Center

18 October 2019

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10.2.4 Calibration protocol v_5

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Deutsche Wir Wind Tunnel	ndGuard Services GmbH	RE and MEASNET approved te	st laboratory
accredited by the / a	akkreditiert durch die		
Deutsche Akk as calibration labora	tory in the / als Kalibrierlaborator	ium im	S kreditierungsstelle Kr5140-01-00
Deutschen Ka	librierdienst	KD	1711469 D-К-
Calibration certificat Kalibrierschein	e	Calibration mark Kalibrierzeichen	15140-01-00 03/2017
Object Gegenstand	Cup Anemometer	This calibration certificate of traceability to national standard	locuments the ls, which realize
Manufacturer Hersteller	Thies Clima D-37083 Göttingen	the units of measurement ac International System of Units (SI) The DAkkS is signatory to t	cording to the
Type Typ	4.3351.00.000	agreements of the European of Accreditation (EA) and of the Laboratory Accreditation Cooper	e Internation for ation (ILAC) for
Serial number Fabrikat/Serien-Nr.	03176369	the mutual recognition of calibra The user is obliged to ha recalibrated at appropriate interv	tion certificates. ve the object rals.
Customer Auftraggeber	UL International GmbH - DEWI D-26382 Wilhelmshaven	Dieser Kolibrierschein dokumen führung auf nationale Normale der Einheiten in Übereinstime	itiert die Rück- zur Darstellung nung mit dem
Order No. Auftrogsnummer	88371002454	Internationalen Einheitensystem Die DAkkS ist Unterzeichner de Übereinkommen der European	(SI). r multilateralen ca:ageration for
Project No. Projektnummer	VT170352	Accreditation (EA) und der Laboratory Accreditation Cooper	International ation (ILAC) zur
Number of pages Anzahl der Seiten	4	gegenseitigen Anerkennung der Für die Einhaltung einer angeme Wiederhalung der Kalibrierung	Kolibrierscheine. Issenen Frist zur Ist der Benutzer
Date of Calibration	30.03.2017	verantwortlich.	st der benutzer

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Page 2 / 4		D-9
Seite		15140-
		03/2
Calibration object Kalibriergegenstand	Cup Anemometer	
Calibration procedure Kalibrierverfahren	Deutsche WindGuard Wind Based on following standards:	funnel Services: QM-KL-AK-VA
	MEASNET: Anemometer cali	bration procedure
	wind turbines	rmance measurements of electricity produc
	 IEC 61400-12-2: Power performance 	rmance of electricity producing wind turbin
	 ISO 3966: Measurement of f 	uid in closed conduits
	 ISO 16622: Meteorology - So 	nic anemometers/thermometers
Place of calibration Ort der Kalibrierung	Windtunnel of Deutsche Wind	Guard WindTunnel Services GmbH, Varel
Test conditions	wind tunnel area	10000 cm ²
	anemometer frontal area	230 cm ²
	diameter of mounting pipe	34 mm
	blockage ratio 1)	0.023 [-]
	software version	7.64
	Due to the special construction of the	e test section no blockage correction is necessary.
Ambient conditions Umgebungsbedingungen	air temperature	23.5 °C±0.1 °C
	air pressure	1021.3 hPa ± 0.3 hPa
	relative air humidity	37.9 % ± 2.0 %
Measurement uncertainty Measunsk/herheit	The expanded uncertainty assi multiplying the standard uncer determined in accordance with within the assigned range of v. The reference flow speed mea (Physikalisch-Technische Bund by using a PTB owned and calil Uncertainty 0.2 %, !=2)	gned to the measurement results is obtained tainty by the coverage factor k = 2. It has be DAKdS-DKD-3. The value of the measurand Jules with a probability of 95%, surement is traceable to the German NMI esanstalt) standard for flow speed. It is realis rated Laser Doppler Anemometer (Standard
Additional remarks	-	
zusatziiche Anmerkungen		

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Page 3/4					D-K-
Sevite					15140-01-00
					03/2017
Calibration Kolibrierergeb	result nis				
	Sensor output	Tunnel spe	ed L	Incertainty (k-2)	
	Hz	m/s		m/s	
	82.207	3.996		0.050	
	123.522	5.911		0.050	
	166.688	7.909		0.051	
	210.496	9.921		0.051	
	254.161	11.955		0.052	
	296.054	13.877		0.052	
	339.766	15.882		0.053	
	318.287	14.860		0.053	
	275.810	12.953		0.051	
	231.348	10.921		0.052	
	187.419	8.888		0.051	
	145.107	6.947		0.051	
	102.450	4.951		0.050	
statistical a	inalysis	Slope	0.04607 (m/s)/(Hz) ±0.00	0007 (m/s)/(H	r)
		Standard orror (V)	0.2339 m/s ±0.016 m/s		
		Correlation coefficient	0.999987		
Pomorke		The collinger of second second	and the second sec	10	
Remarks		demanded linearity of Mi	ASNET	WindG	ard
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				XTH	
			uts		Phila
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Deutsche WindGuard Wind Tunnel Services GmbH, Varel

WINDGUARD

10.3 Wind vane calibration protocol

10.3.1 Calibration protocol dir₁

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Excredied by the lokkreditier durch die bescheche Akkreditier aungestelle Gundin is die factor is how of all konter is die bescher is die b	eutsche Win Vind Tunnel	dGuard Services GmbH IEC	RE and MEASNET approved test laboratory	Calibration object Kolibriergegenstand	Wind Vane	
Concernance of the function of the func	energian discales (-	the distant death die		Calibration procedure Kolibrierverfahren	IEC 61400-12-1:2017	
	eutsche Akk	reditierungsstelle Gm	bH	Place of calibration Ort der Kalibrierung	Wind tunnel of Deutsche Wind	Guard WindTunnel Services GmbH, Varel
$ \begin{array}{c} the state of the sta$	s calibration laborat	ory in the / als Kalibrierlaborator	ium im	Test conditions	wind tunnel area	10000 cm ²
Additional certificate individuality in the subject individuality individuality in the subject individuality individuality individuality in the subject individuality individualit			D-4-15140-01-00	niessbedingungen	anemometer frontal area	200 cm ²
alibration certificate Calibration mark faibure scales District Statup - Statup - Statup - S	Jeutschen Ka	librierdienst	1922036		diameter of mounting pipe	33.7 mm
alloration certificate Calibration mark Kalibrierschein 10:400-100 (05/2013) biget remainder Wind Vane This calibration certificate to technickly in attoint stationt, which realise to the terrational System of Usits (0). viget remainder This calibration certificate to technickly in attoint station, which realise to the terrational System of Usits (0). viget remainder The context is context in the technickly in attoint station which realise to the terrational System of Usits (0). viget remainder 0.13004350 viget remainder context in the terrational System of Usits (0). viget remainder 0.13004450 viget remainder context in the terrational System of Usits (0). viget remainder context in the terrational System of Usits (0). viget remainder context in the terrational System of Usits (0). viget remainder context in the terrational System of Usits (0). viget remainder context in the terrational System of Usits (0). viget remainder context in the terrational System of Usits (0). viget remainder context in the terrational System of Usits (0). viget remainder context in the terrational Context in the terrational System of Usits (0). viget remainder context in the terrational Context in the terrational Context in the terrational System of Usits (0). viget remainder context in the terrational Context in th			D-K-		blockage ratio 1	0.020 [-]
minimum dependence Rollbeiteraction [6/2019] Vigle Wind Vane This calibration certificate documents the traceability to actional standard, which realize brandard. This calibration certificate documents the traceability to actional standard, which realize brandard. The DABS is separatory to the multiliareral agreement according to the interactional System of Units (S). air temperature 26.2 °C ± 0.1 °C air pressure yper or all number of al	alibration certificate	2	Calibration mark 15140-01-00		software version	P 80.03
Depict of spectral spectra spectra spectral spectral spectral spectral spectral	monerschein		Kalibrierzeichen 06/2019		¹⁾ Due to the special construction of th	test section on blockage correction is necessary
Note: The control of the climation of th	biect	Wind Vana	This calibration certificate documents the			contraction of the state of the
desurfacture instruction The sc Clima problem (b) 2038 Gittingen De units of measurement according to the measurements of the furnession (50). discrete (b) air pressure (b) <	iegenstand	wind vane	traceability to national standards, which realize	Ambient conditions	air temperature	26.2 °C ± 0.1 °C
pre- pre- pre- pre- pre- pre- pre- pre-	Aanufacturer	Thies Clima	International System of Units (SI).	on general and a g	air pressure	1010.1 hPa ± 0.3 hPa
ype 4.3151.00.212 Accreditation (FA) and of the intervalues is dimensional distance of the intervalues Laboratory Accreditation (CA) and of the intervalues uborner 06130414 The expanded uncertainty by the coverage factor w2. It has be determined in the intervalues uborner U. Intervational GmbH - DEWI Disters the additional intervalue Descent Millional Combiner Disters the additional intervalue The expanded uncertainty by the coverage factor w2. It has be determined in the additional intervalue of the measurement is recalled to Experiment is recalled to Experimation is advectory is advectory is advectory is advectory is adv	and the second sec	D-37083 Göttingen	The DAkkS is signatory to the multilateral agreements of the European co-operation for		relative air humidity	62.6 % ± 2.0 %
Production Description Measurement uncertainty Measurement uncertainty Additional remarks and/uncertainty 0619041.4 The use is object The use is object Machine Destance The use is object The use is object Machine Destance The use is object Machine The expanded or the machine The expanded or the machine Machine The expanded or the machine The expanded or the machine Machine The expanded or the malin full	уре	4.3151.00.212	Accreditation (EA) and of the International			
Person number (bigspace/second (bigspace/second) DB 90-014 The user is obliged to have the object recalibration is considered as apporting intervals. Durber No. 10-06382 The user is obliged to have the object recalibration is considered as apporting intervals. Durber No. 10-06382 The user is obliged to have the object recalibration is considered as apporting intervals. Durber No. 10-06382 The user is obliged to have the object recalibration is considered as apporting intervals. Durber No. 10-06382 The user is obliged to have the object recalibration is considered as apporting intervals. Durber No. 10-06382 The user is object to number of page. 6 Derein Main the assigned range of values with a probability of 95%. Durber No. 10-06383 Mile Standard uncertainty by the coverage factor #2.1 has be determined in the assigned range of values with a probability of 95%. The user of page. 6 Mile Standard uncertainty by the object intervals. Mile Standard uncertainty by the overage factor #2.1 has be determined in the assigned range of values with a probability of 95%. The user of page. 6 Mile Standard uncertainty by the overage factor #2.1 has be determined in the same of the subject of the same of the subject of the same of the subject of the subje	π.		Laboratory Accreditation Cooperation (ILAC) for the mutual recognition of calibration certificates.	Measurement uncertainty Measuresicherheit	The expanded uncertainty ass	gned to the measurement results is obtained
Database UL International GmbH - DEWI D-25832 WithelmSaven Discer Kolliseration (Privation de molecular bioleration) Discer Kolliseration (Privation de molecular bioleration) Without the assigned name of values with a probability of 95%. The reference for sogeed measurement is traceable to the German Number of collibration Without the assigned name of values with a probability of 95%. The reference for sogeed measurement is traceable to the German Number of collibration Without the assigned name of values with a probability of 95%. The reference for sogeed measurement is traceable to the German Number of collibration Without the assigned name of values with a probability of 95%. The reference for sogeed measurement is traceable to the German Number of collibration Without the assigned name of values with a probability of 95%. The reference for sogeed measurement is traceable to the German Number of pages of the following of collibration of the following is de following is de following is de following is de following werantwortich. Without the same of the following is de following is de following werantwortich. Mittee following is de following werantwortich. Bits calibration certificate may not be reprodued other than in full exceptibility of a comparison internation of subleming und with a same page. Bits calibration certificate may not be reprodued other than in full exceptibility of a comparison werantwortich. Bits calibration certificate may not be reprodued other than in full exceptibility de following is deb following werantwortich. Bits calibration certificate may not be demonstration werantwortich. Bits calibration certificate may not be demonstrating measuremated to backbon document elabetrification may measurem	abrikat/Serien-Nr.	06190414	The user is obliged to have the object		determined in accordance wit	rtainty by the coverage factor k=2. It has been h DAkkS-DKD-3. The value of the measurand l
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ation resu	it (1/3) 3)						Calibration resul Kalibrierergebnis (2/	t (2/3)	
Reference	Reference	Reference	Reference	Test item	Test item	Test item	Reference	Reference	Re
Air velocity	Unc	Yaw angle	Unc	Source	Wiper	Ratio	Air velocity	Unc	Ya
m/s	m/s	deg	deg	v	v		m/s	m/s	
8.00	0.05	5.01	0.80	8.000	0.129	0.0162	8.00	0.05	
7.99	0.05	10.02	0.90	8.000	0.242	0.0302	8.00	0.05	
8.00	0.05	15.00	0.80	8.000	0.353	0.0441	7.99	0.05	
8.00	0.05	19.95	0.80	8.000	0.464	0.0580	7.99	0.05	
7.99	0.05	24.61	0.80	8.000	0.567	0.0709	8.00	0.05	
8.00	0.05	30.04	0.90	8.000	0.689	0.0861	7.99	0.05	
7.99	0.05	35.00	0.80	8.000	0.798	0.0998	7.99	0.05	
8.00	0.05	39.98	0.80	8.000	0.910	0.1137	8.00	0.05	
8.00	0.05	40.06	0.80	8.000	1.025	0.1282	7.99	0.05	
7.99	0.05	50.08	0.80	8.000	1.158	0.1423	7.99	0.05	
7.99	0.05	60.10	0.80	8.000	1.245	0.1381	7.99	0.05	
8.00	0.05	65.17	0.80	8.000	1.476	0.1845	8.00	0.05	
7.99	0.05	70.09	0.80	8.000	1.585	0.1981	7.99	0.05	
7.99	0.05	75.03	0.80	8.000	1.696	0.2120	7.99	0.05	
7.99	0.05	79.99	0.80	8.000	1.807	0.2258	7.99	0.05	
7.99	0.05	84.98	0.80	8.000	1.917	0.2397	7.99	0.05	
7.99	0.05	90.02	0.80	8.000	2.029	0.2537	8.00	0.05	
7.99	0.05	95.01	0.80	8.000	2.141	0.2676	7.99	0.05	
8.00	0.05	100.02	0.80	8.000	2.253	0.2816	7.99	0.05	
8.00	0.05	105.00	0.80	8.000	2.363	0.2953	8.00	0.05	
7.99	0.05	109.93	0.80	8.000	2.472	0.3090	7.99	0.05	
7.99	0.05	114.95	0.80	8.000	2.584	0.3230	8.00	0.05	
7.99	0.05	119.96	0.80	8.000	2.695	0.3369	7.99	0.05	
7.99	0.05	124.96	0.80	8.001	2.806	0.3508	7.99	0.05	
7.99	0.05	129.96	0.80	8,000	2.918	0.3647	. 7.39	0.05	
8.00	0.05	140.00	0.80	8,000	3.029	0.3/87	8.00	0.05	
8.00	0.05	145.01	0.80	8,000	3.253	0.3925	8.00	0.05	
7.99	0.05	149.91	0.80	8,000	3.361	0.4201	8.00	0.05	
7.99	0.05	154.97	0.80	8.000	3.472	0.4340	8.00	0.05	

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Calibration result Kalibrierergebnis (2/3,	(2/3)					
Reference	Reference	Reference	Reference	Test item	Test item	Test item
Air velocity	Unc	Yaw angle	Unc	Source	Wiper	Ratio
m/s	m/s	deg	deg	v	v	
8.00	0.05	160.02	0.80	8.000	3.583	0.4479
8.00	0.05	164.97	0.80	8.000	3.693	0.4617
7.99	0.05	170.00	0.80	8.000	3.805	0.4755
7.99	0.05	174.95	0.80	8.000	3.915	0.4894
8.00	0.05	179.95	0.80	8.000	4.028	0.5035
7.99	0.05	185.01	0.80	8.000	4.140	0.5174
7.99	0.05	190.00	0.80	8.000	4.252	0.5315
8.00	0.05	195.04	0.80	8.000	4.365	0.5456
7.99	0.05	200.04	0.80	8.000	4.475	0.5594
7.99	0.05	204.94	0.80	8.000	4.587	0.5734
7.99	0.05	210.00	0.80	8.000	4.700	0.5874
7.99	0.05	215.05	0.80	8.000	4.813	0.6016
8.00	0.05	220.03	0.80	8.000	4.923	0.6153
7.99	0.05	225.04	0.80	8.000	5.035	0.6293
7.99	0.05	230.05	0.80	8.000	5.146	0.6432
7.99	0.05	235.03	0.80	8.000	5.258	0.6573
7.99	0.05	239.95	0.80	8.000	5.369	0.6711
8.00	0.05	245.00	0.80	8.000	5.480	0.6850
7.99	0.05	250.04	0.80	8.000	5.590	0.6987
7.99	0.05	255.01	0.80	8.000	5.702	0.7127
8.00	0.05	260.03	0.80	8.000	5.813	0.7266
7.99	0.05	265.02	0.80	8.000	5.924	0.7405
8.00	0.05	270.07	0.80	8.000	6.037	0.7546
7.99	0.05	275.05	0.80	8.000	6.146	0.7682
7.99	0.05	279.99	0.80	8.000	6.255	0.7818
7.99	0.05	285.05	0.80	8.000	6.368	0.7959
8.00	0.05	290.01	0.80	8.000	6.474	0.8092
8.00	0.05	295.02	0.80	8.000	6.577	0.8221
8.00	0.05	300.04	0.80	8.000	6.690	0.8362
8.00	0.05	304.95	0.80	8.000	6.800	0.8499
8.00	0.05	309.98	0.80	8.000	6.912	0.8540

10.3.2 Calibration protocol dir₂

This calibration certificate may not be reproduced other than in full except with the permission of both the German Accretations floxy and the issuing laboratory. Calibration certificates without signature are not valid. This calibration (Dear Kalibrinshead) and for an oblitation gui on unreindence venterwheristie verseful. Accusing on AcArdemizingen heating net Generhalings served) der Devatione Akzetteringstelle eils such des austellenden köllbertaboratoriums. Kalibrierscheine dere Unterschrift hende keine Gälligkeit. Dieser köllerscheide wurde leitkonsche Rezugt.

Date Dotum	Head of the calibration laboratory Leiter des Kolibrierlaboratoriums	Person in charge Bearbeiter	
20.06.2019	D. Jostomus	Schut	
	Dipl. Phys. Dieter Westermann	Kai Schuster, B. Eng.	

			1922025
Daga 2 / 6			1922033 D-K-
Fage 27 0 Seite			15140-01-0
			06/2019
Calibration object	Wind Vane		
Kalibriergegenstand			
Calibration procedure Kalibrierverfahren	IEC 61400-12-1:2017		
Place of calibration Ort der Kollbrierung	Wind tunnel of Deutsche Wind	Guard WindTunnel Services G	imbH, Varel
Test conditions	wind tunnel area	10000 cm ²	
Messbedingungen	anemometer frontal area	200 cm ²	
	diameter of mounting pipe	33.7 mm	
	blockage ratio 1)	0.020 [-]	
	software version	P_8.0.03	
	¹⁾ Due to the special construction of th	e test section no blockage correction	is necessary.
Ambient conditions	air temperature	26.1 °C ± 0.1 °C	
omgebangsbeamgungen	air pressure	1009.8 hPa ± 0.3 hPa	
	relative air humidity	62.8 % ± 2.0 %	
Measurement uncertainty Measunsicherheit	The expanded uncertainty assi multiplying the standard uncer determined in accordance with within the assigned range of vu The reference flow speed mea (Physikalisch-Technische Bund by using a PTB owned and calit Uncertainty 0.2 %, <i>k=2</i>)	gned to the measurement res tainty by the coverage factor. I DAkkS-DKD-3. The value of th lues with a probability of 95% surement is traceable to the G esanstalt] standard for flow sp rated Laser Doppler Anemor	ults is obtained by k=2. It has been he measurand lies is ierman NMI weed. It is realized weter (Standard
Additional remarks Zusätzliche Anmerkungen			
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age 3 / 6 He						1922035 D-K- 15140-01-00 06/2019
Calibration resultation resultation resultation (1	ult (1/3) /3)					
Reference	Reference	Reference	Reference	Test item	Test item	Test item
Air velocity	Unc	Yaw angle	Unc	Source	Wiper	Ratio
m/s	m/s	deg	deg	v	v	· · ·
7.90	0.05	5.02	0.80	7.999	0.104	0.0130
7.90	0.05	10.03	0.80	7.999	0.215	0.0268
7.90	0.05	15.03	0.80	7.999	0.327	0.0408
7.90	0.05	19.98	0.80	7.999	0.436	0.0545
7.90	0.05	24.65	0.80	7.999	0.538	0.0672
7.90	0.05	30.02	0.80	7.999	0.657	0.0821
7.90	0.05	34.97	0.80	7.999	0.765	0.0956
7.90	0.05	39.96	0.80	7.999	0.877	0.1096
7.90	0.05	45.08	0.80	8.000	0.993	0.1241
7.91	0.05	50.09	0.80	7.999	1.105	0.1381
7.90	0.05	55.01	0.80	7.999	1.215	0.1519
7.90	0.05	60.03	0.80	7.999	1.326	0.1658
7.90	0.05	65.06	0.80	7.999	1.438	0.1798
7.90	0.05	70.03	0.80	7.999	1.549	0.1936
7.90	0.05	75.02	0.80	7.999	1.659	0.2074
7.90	0.05	80.07	0.80	7.999	1.772	0.2215
7.90	0.05	85.05	0.80	7.999	1.881	0.2352
7.90	0.05	89.96	0.80	7.999	1.991	0.2488
7.90	0.05	94.97	0.80	7.999	2.104	0.2630
7.90	0.05	100.00	0.80	7.999	2.215	0.2769
7.90	0.05	104.98	0.80	8.000	2.325	0.2906
7.90	0.05	109.95	0.80	7.999	2.435	0.3044
7.90	0.05	114.97	0.80	7.999	2.547	0.3184
7.90	0.05	120.00	0.80	7.999	2.658	0.3323
7.90	0.05	125.03	0.80	7.999	2.770	0.3463
7.91	0.05	129.97	0.80	7.999	2.879	0.3599
7.90	0.05	134.98	0.80	8.000	2.990	0.3738
7.90	0.05	139.95	0.80	7.999	3.102	0.3878
7.90	0.05	145.00	0.80	8.000	3.213	0.4017
7.90	0.05	149.97	0.80	7.999	3.323	0.4154
7.90	0.05	154.92	0.80	8.000	3.434	0.4292
utsche Wind	Guard				D	UTSCHE

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Calibration resu Kolibrierergebnis (2)	ilt (2/3) /3/					
Reference	Referer ce	Beference	Reference	Test item	Test item	Tost item
Air velocity	Unc	Yaw angle	Unc	Source	Wiper	Ratio
m/s	m/s	deg	deg	v	v	-
7.90	0.05	159.96	0.80	7.999	3.545	0.4431
7.90	0.05	164.99	0.80	7.999	3.656	0.4570
7.90	0.05	169.95	0.80	7.999	3.767	0.4710
7.90	0.05	174.98	0.80	7.999	3.890	0.4850
7.90	0.05	180.00	0.80	7.999	3.991	0.4989
7.90	0.05	184.99	0.80	8.000	4.103	0.5129
7.90	0.05	189.97	0.80	7.999	4.213	0.5266
7.90	0.05	195.00	0.80	7.999	4.323	0.5404
7.90	0.05	200.03	0.80	8.000	4.436	0.5545
7.91	0.05	204.96	0.80	7.999	4.545	0.5682
7.90	0.05	209.98	0.80	7.999	4.657	0.5822
7.90	0.05	215.04	0.80	7.999	4.771	0.5964
7.90	0.05	220.04	0.80	8.000	4.882	0.6103
7.90	0.05	224.99	0.80	8.000	4.991	0.6240
7.90	0.05	230.03	0.80	8.000	5.104	0.6380
7.91	0.05	235.02	0.80	7.999	5.216	0.6520
7.90	0.05	239.95	0.80	8.000	5.326	0.6658
7.90	0.05	244.98	0.80	7.999	5.438	0.6799
7.90	0.05	249.97	0.80	8.000	5.548	0.6936
7.91	0.05	255.00	0.80	7.999	5.659	0.7075
7.91	0.05	260.05	0.80	8.000	5.772	0.7216
7.90	0.05	265.01	0.80	8.000	5.884	0.7355
7.90	0.05	270.04	0.80	8.000	5.996	0.7495
7.90	0.05	275.04	0.80	8.000	6.107	0.7634
7.91	0.05	280.04	0.80	8.000	6.218	0.7773
7.90	0.05	285.03	0.80	8.000	6.328	0.7910
7.90	0.05	289.95	0.80	8.000	6.434	0.8043
7.90	0.05	295.02	0.80	8.000	6.541	0.8177
7.90	0.05	300.02	0.80	8.000	6.652	0.8316
7.91	0.05	304.93	0.80	7.999	6.762	0.8454
7.90	0.05	309.93	0.80	8.000	6.875	0.8594

10.3.3 Calibration protocol dir₃

This calibration certificate may not be reproduced other than in full except with the permission of both the German Accreditation Body and the issuing laboratory. Calibration certificates without signature are not valid. This calibration certificate has been generated electronically. Others Kollaberischein darf um volkstindig und unverdindert weiterverhreitet werden. Auszige oder Änderungen bedürfen der genehningung sowid der Deutschen Akterläteringsnatule of auch des ousstellenden Kollaberischotororiums. Kollaberischeine ohne Unterschrift haben keine Gültigkeit. Dieser Kollaberischein wurde elektronisch erzeugt.

Date Datum	Head of the calibration laboratory Leiter des Kalibrierlaboratoriums	Person in charge Bearbeiter	
20.06.2019	D. Jostomm	Solut	
	Dipl. Phys. Dieter Westermann	Kal Schuster, B. Eng.	

		192203
2000 2 / 6		D-K-
elte		15140-01
		06/201
Calibration object Kalibriergegenstand	Wind Vane	
Calibration procedure Kolibrienverfahren	IEC 61400-12-1:2017	
Place of calibration Ort der Kolibrierung	Wind tunnel of Deutsche Wind	Guard WindTunnel Services GmbH, Varel
Test conditions	wind tunnel area	10000 cm ²
messoeungungen	anemometer frontal area	200 cm ²
	diameter of mounting pipe	33.7 mm
	blockage ratio 1)	0.020 [-]
	software version	P_8.0.03
	¹⁾ Due to the special construction of th	e test section no blockage correction is necessary.
Ambient conditions	air temperature	26.0 °C ± 0.1 °C
ningebon gube anigangen	air pressure	1009.7 hPa ± 0.3 hPa
	relative air humidity	62.9 % ± 2.0 %
Measurement uncertainty Messunsicherheit	The expanded uncertainty assign multiplying the standard uncer determined in accordance with within the assigned range of va The reference flow speed meas (Physikalisch-Technische Bundi by using a PTB owned and calit Uncertainty 0.2 %, <i>k=2</i>)	gned to the measurement results is obtained i tainty by the coverage factor <i>i=2</i> . It has been DAKKS-DKD-3. The value of the measurand lii lues with a probability of 95%. urement is traceable to the German NMI esanstalt) standard for flow speed. It is realize rated Laser Doppler Anemometer (Standard
Additional remarks		
Revision	0	
Revision		

age 3 / 6 ite					1922034 D-К- 15140-01-00	
						06/2019
libration resu	lt (1/3)					
Reference	Reference	Reference	Reference	Test item	Test item	Test item
Air velocity	Unc	Yaw angle	Unc	Source	Wiper	Ratio
m/s	m/s	deg	deg	v	v	-
7.91	0.05	5.02	0.80	8.000	0.097	0.0121
7.90	0.05	10.01	0.80	8.000	0.208	0.0260
7.90	0.05	14.98	0.80	8.000	0.320	0.0400
7.90	0.05	19.96	0.80	8.000	0.431	0.0539
7.90	0.05	24.64	0.80	8.000	0.535	0.0669
7.90	0.05	30.00	0.80	8.000	0.654	0.0817
7.90	0.05	34.97	0.80	8.000	0.763	0.0954
7.91	0.05	39.99	0.80	8.000	0.874	0.1093
7.90	0.05	45.00	0.80	8.000	0.988	0.1235
7.90	0.05	49.98	0.80	8.000	1.101	0.1376
7.90	0.05	55.00	0.80	8.000	1.212	0.1515
7.91	0.05	60.04	0.80	8.000	1.325	0.1657
7.90	0.05	65.02	0.80	8.000	1.436	0.1795
7.90	0.05	70.00	0.80	8.001	1.547	0.1934
7.90	0.05	75.04	0.80	8.001	1.658	0.2072
7.90	0.05	80.00	0.80	8.001	1.769	0.2211
7.90	0.05	84.98	0.80	8.001	1.880	0.2350
7.90	0.05	90.00	0.80	8.001	1.990	0.2487
7.90	0.05	95.00	0.80	8.000	2.103	0.2628
7.90	0.05	100.00	0.80	8.001	2.215	0.2768
7.90	0.05	105.04	0.80	8.001	2.326	0.2908
7.90	0.05	110.08	0.80	8.001	2.437	0.3046
7.90	0.05	115.06	0.80	8.001	2.549	0.3186
7.90	0.05	120.04	0.80	8.000	2.660	0.3324
7.90	0.05	125.00	0.80	8.001	2.770	0.3463
7.90	0.05	130.02	0.80	8.001	2.882	0.3602
7.90	0.05	134.99	0.80	8.001	2.992	0.3739
7.90	0.05	139.98	0.80	8.001	3.103	0.3878
7.90	0.05	144.96	0.80	8.001	3.214	0.4017
7.90	0.05	150.00	0.90	8.000	3.325	0.4156
7.90	0.05	155.02	0.80	8.001	3.438	0.4297
itsche Wind	Guard		-		DE	UTSCHE

Page 4 / 6 Calibration result (2/3) Exhiberergenomic (2/3) Reference Al velocity Reference Unc Reference New Media Reference Unc Reference New Media Reference Unc Reference Source Reference Unc Reference New Media Reference Unc Reference Source Reference Unc Reference New Media Reference Unc Reference Source Reference Unc Reference Source Reference Source Reference Unc Reference Source Reference Source <t< th=""><th>Im Test Item Test Item Ratio</th><th>Test item</th><th></th><th></th><th>ult (2/3)</th><th>Page 4 / 6 Seite</th></t<>	Im Test Item Test Item Ratio	Test item			ult (2/3)	Page 4 / 6 Seite
Senior Reference Reference Reference Reference Reference Reference Reference Source Markenno Markenno Markenno New angle Unc Test item Markenno Unc Tese angle Unc Source Mr Mark deg deg V 7.90 0.05 140.00 0.80 8.001 7.90 0.05 170.00 0.80 8.001 7.90 0.05 175.02 0.80 8.001 7.90 0.05 155.01 0.80 8.001 7.90 0.05 155.01 0.80 8.001 7.90 0.05 155.01 0.80 8.001 7.90 0.05 210.02 0.80 8.001 7.90 0.05 214.99 0.80 8.001 7.90 0.05 224.03 0.80 8.001 7.90 0.05 224.03 0.80 8.001 7.90	15140- 06/2 Im Test Item Test Item x Wijer Ratio	Test item			ult (2/3)	Seite
Alignmenuposes Reference Reference Reference Reference Selference Arwenchy Unc Yaw angle Unc Source m/s Meg Meg Meg Meg Source m/s Meg Meg Meg Meg Meg Source m/s Meg	06/21 2m Test Item Test Item 2e Wijer Ratio	Test Item			ult (2/3)	
Calibration result (2/3) Reference Arvetocity Reference Unc Reference Wave Reference May Reference Wave	im Testitem Testitem 28 Wiper Ratio	Test item			ult (2/3)	
Calibration casult (2/3) Reference Air vector Reference with m/s Reference m/s Reference with m/s Reference m/s Reference with m/s Test test m/s m/s m/s m/s Reference with m/s Reference with m/s <th>im Testitem Testikem x Wiper Ratio</th> <th>Test Item</th> <th></th> <th></th> <th>ult (2/3)</th> <th></th>	im Testitem Testikem x Wiper Ratio	Test Item			ult (2/3)	
Reference Reference Reference Reference Reference Server Arvetechy Unc Yaw angle Unc Source m/n 6g 6g <th>em Test item Test item 28 Wiper Ratio</th> <th>Test item</th> <th></th> <th></th> <th>/3)</th> <th>Calibration resu Kolibrierergebnis (2)</th>	em Test item Test item 28 Wiper Ratio	Test item			/3)	Calibration resu Kolibrierergebnis (2)
Arrestory Une Yas angle Une Gaura m/s m/s 66g 46g V 730 0.05 140.00 0.80 8202 730 0.05 144.07 0.80 8202 730 0.05 154.97 0.80 8202 730 0.05 175.02 0.80 8201 730 0.05 175.92 0.80 8201 730 0.05 125.01 0.80 8201 730 0.05 126.01 0.80 8201 730 0.05 120.02 0.80 8201 730 0.05 220.03 0.80 8201 730 0.05 221.02 0.80 8201 730 0.05 224.93 0.80 8201 730 0.05 224.93 0.80 8201 730 0.05 224.93 0.80 8201 730 0.05 224.93 0.80 </th <th>on Wiper Ratio</th> <th></th> <th>Reference</th> <th>Reference</th> <th>Reference</th> <th>Reference</th>	on Wiper Ratio		Reference	Reference	Reference	Reference
m/s m/s fdg deg y 7.00 0.05 146.00 0.80 8.001 7.00 0.05 126.00 0.80 8.001 7.00 0.05 179.00 0.80 8.001 7.00 0.05 179.00 0.80 8.001 7.00 0.05 179.95 0.80 8.001 7.90 0.05 125.01 0.80 8.001 7.90 0.05 125.01 0.80 8.001 7.90 0.05 120.01 0.80 8.001 7.90 0.05 220.02 0.80 8.001 7.90 0.05 224.99 0.80 8.001 7.90 0.05 220.03 0.80 8.001 7.90 0.05 224.99 0.80 8.001 7.90 0.05 220.03 0.80 8.001 7.90 0.05 224.97 0.80 8.001 7.90 0.05 224.97 <td>v</td> <td>Source</td> <td>Unc</td> <td>Yaw angle</td> <td>Unc</td> <td>Air velocity</td>	v	Source	Unc	Yaw angle	Unc	Air velocity
790 0.05 140.00 0.06 80.01 790 0.05 144.97 0.80 80.01 750 0.05 175.02 0.80 80.01 750 0.05 175.92 0.80 80.01 750 0.05 175.92 0.80 80.01 750 0.05 179.55 0.80 80.01 750 0.05 190.01 0.80 80.01 780 0.05 20.02 0.80 80.01 780 0.05 20.02 0.80 80.01 780 0.05 22.02 0.80 80.01 780 0.05 22.02 0.80 80.01 780 0.05 22.99 0.80 80.01 780 0.05 22.03 0.80 80.01 780 0.05 22.03 0.80 80.01 780 0.05 22.03 0.80 80.01 780 0.05 22.05	v -	v	deg	deg	m/s	m/s
7.00 0.05 14.47 0.00 8.001 7.00 0.05 170.00 0.80 8.001 7.00 0.05 173.92 0.80 6.001 7.00 0.05 173.95 0.80 6.001 7.90 0.05 135.00 0.80 6.001 7.30 0.05 135.01 0.80 6.001 7.80 0.05 20.01 0.80 6.001 7.80 0.05 20.01 0.80 6.001 7.80 0.05 20.02 0.80 6.001 7.80 0.05 21.49 0.80 6.001 7.80 0.05 224.93 0.80 6.001 7.80 0.05 224.93 0.80 6.001 7.80 0.05 224.93 0.80 6.001 7.80 0.05 224.93 0.80 6.001 7.80 0.05 224.93 0.80 6.001 7.80 0.05 224.	1 3.549 0.4436	8.001	0.80	160.00	0.05	7.90
7.00 0.05 170.00 0.06 8.001 7.00 0.05 175.02 0.80 8.001 7.00 0.05 179.95 0.80 8.001 7.90 0.05 185.00 0.80 8.001 7.90 0.05 195.01 0.80 8.001 7.90 0.05 195.01 0.80 8.001 7.90 0.05 20.01 0.80 8.001 7.90 0.05 20.45 0.80 8.001 7.90 0.05 21.02 0.80 8.001 7.90 0.05 224.99 0.80 8.001 7.90 0.05 220.03 0.80 8.001 7.90 0.05 220.03 0.80 8.001 7.90 0.05 220.03 0.80 8.001 7.90 0.05 220.03 0.80 8.001 7.90 0.05 220.97 0.80 8.001 7.90 0.05 22	1. 3.659 0.4574	8.001	0.80	164.97	0.05	7.90
no 0.05 175.02 0.08 6.001 750 0.05 179.85 0.08 6.001 731 0.05 129.01 0.90 6.001 730 0.05 129.01 0.90 6.001 730 0.05 129.01 0.90 6.001 740 0.05 129.01 0.90 6.001 750 0.05 220.02 0.80 6.001 750 0.05 224.93 0.80 6.001 750 0.05 224.93 0.80 6.001 750 0.05 224.03 0.80 6.001 750 0.05 224.03 0.80 6.001 750 0.05 224.93 0.80 6.001 750 0.05 224.93 0.80 6.001 760 0.05 224.93 0.80 6.001 760 0.05 254.97 0.80 6.001 7740 0.05 254.97	1 3.770 0.4712	8.001	0.80	170.00	0.05	7.90
7.90 0.05 17.95 0.00 8.001 7.90 0.05 185.00 0.80 6.001 7.90 0.05 195.01 0.80 6.001 7.90 0.05 195.01 0.80 6.001 7.90 0.05 200.01 0.80 6.001 7.90 0.05 210.02 0.80 6.001 7.90 0.05 214.99 0.80 6.001 7.90 0.05 224.99 0.80 6.001 7.90 0.05 224.93 0.80 6.001 7.90 0.05 224.93 0.80 6.001 7.90 0.05 239.98 0.80 6.001 7.90 0.05 239.98 0.80 6.001 7.90 0.05 239.98 0.80 6.001 7.90 0.05 239.98 0.80 6.001 7.90 0.05 239.99 0.80 8.001 7.90 0.05	1 3.883 0.4853	8.001	0.80	175.02	0.05	7.90
1 0.05 135.00 0.08 6.001 7500 0.05 190.01 0.80 6.001 730 0.05 190.01 0.80 6.001 730 0.05 20.01 0.80 6.001 730 0.05 20.43 0.80 6.001 730 0.05 214.90 0.80 6.001 730 0.05 214.90 0.80 6.001 730 0.05 224.92 0.80 6.001 730 0.05 224.93 0.80 6.001 740 0.05 224.97 0.80 6.001 750 0.05 230.3 0.80 6.001 740 0.05 230.93 0.80 6.001 750 0.05 254.97 0.80 6.001 750 0.05 254.97 0.80 6.001 750 0.05 254.97 0.80 6.001 750 0.05 254.97	1 3.992 0.4990	8.001	0.80	179.95	0.05	7.90
7.90 0.05 1.95.01 0.80 8.001 7.90 0.05 1.95.01 0.80 8.001 7.90 0.05 20.48 0.80 8.001 7.90 0.05 20.48 0.80 8.001 7.90 0.05 22.02 0.80 8.001 7.90 0.05 22.99 0.80 8.001 7.90 0.05 22.90 0.80 8.001 7.90 0.05 22.90 0.80 8.001 7.90 0.05 22.90 0.80 8.001 7.90 0.05 23.98 0.80 8.001 7.90 0.05 23.98 0.80 8.001 7.90 0.05 25.05 0.80 8.001 7.90 0.05 25.497 0.80 8.001 7.90 0.05 25.497 0.80 8.001 7.90 0.05 25.497 0.80 8.001 7.90 0.05 25.497<	4.105 0.5130	8.001	0.80	185.00	0.05	7.91
19.00 0.05 155.01 0.08 8.001 750 0.05 200.01 0.80 6.001 739 0.05 210.02 0.80 6.001 740 0.05 210.02 0.80 6.001 780 0.05 214.99 0.80 6.001 780 0.05 224.99 0.80 6.001 780 0.05 224.03 0.80 6.001 780 0.05 224.03 0.80 6.001 780 0.05 224.97 0.80 8.001 780 0.05 239.98 0.80 8.001 780 0.05 239.98 0.80 8.001 780 0.05 254.97 0.80 8.001 780 0.05 254.97 0.80 8.001 780 0.05 254.97 0.80 8.001 780 0.05 254.97 0.80 8.001 780 0.05 254.99	4.216 0.5269	8.001	0.80	190.01	0.05	7.90
100 2001 0.00 8001 7500 0.05 204.88 0.00 6.001 730 0.05 21.02 0.80 6.001 730 0.05 21.93 0.80 6.001 730 0.05 21.93 0.80 6.001 740 0.05 225.03 0.80 6.001 750 0.05 224.03 0.80 6.001 750 0.05 224.03 0.80 6.001 750 0.05 239.98 0.80 6.001 750 0.05 239.98 0.80 6.001 760 0.05 239.98 0.80 6.001 770 0.05 254.97 0.80 8.001 730 0.05 254.97 0.80 8.001 740 0.65 254.97 0.80 8.001 730 0.65 254.97 0.80 8.001 740 0.65 254.97 0.80	4.327 0.5409	8.001	0.90	195.01	0.05	7.90
7.90 0.05 20.48 0.80 6.001 7.90 0.05 210.02 0.80 6.001 7.90 0.05 214.99 0.80 6.001 7.90 0.05 219.99 0.80 6.001 7.90 0.05 225.03 0.80 6.001 7.90 0.05 234.97 0.80 6.001 7.90 0.05 234.97 0.80 6.001 7.90 0.05 234.97 0.80 6.001 7.90 0.05 239.88 0.80 6.001 7.90 0.05 254.97 0.80 6.001 7.90 0.05 254.97 0.80 6.001 7.90 0.05 254.97 0.80 6.001 7.90 0.05 254.97 0.80 6.001 7.90 0.65 254.97 0.80 6.001 7.90 0.65 254.97 0.80 6.001 7.90 0.65	4.439 0.5549	8.001	0.90	200.01	0.05	7.90
1.7.00 0.0.05 2.0.02 0.8.00 8.0.01 7.800 0.0.05 2.14.99 0.80 4.6.01 7.700 0.0.05 2.21.99 0.80 4.6.01 7.700 0.0.05 2.22.03 0.80 4.8.01 7.700 0.0.05 2.24.97 0.80 4.8.01 7.700 0.0.05 2.24.97 0.80 4.8.01 7.701 0.0.05 2.24.97 0.80 4.8.01 7.701 0.0.05 2.24.97 0.80 4.8.01 7.701 0.0.05 2.24.97 0.80 6.8.01 7.701 0.0.05 2.24.97 0.80 6.8.01 7.700 0.0.05 2.24.97 0.80 6.8.01 7.700 0.0.05 2.24.97 0.80 6.8.01 7.700 0.0.05 2.24.97 0.80 6.8.01 7.700 0.0.05 2.74.99 0.80 6.8.01 7.700 0.0.05 2.74.99 0.80 6.8.01 <td>4.551 0.5688</td> <td>8.001</td> <td>0.80</td> <td>204.98</td> <td>0.05</td> <td>7,90</td>	4.551 0.5688	8.001	0.80	204.98	0.05	7,90
7.90 0.05 21.49 0.80 8.001 7.90 0.05 219.99 0.80 8.001 7.90 0.05 225.03 0.80 8.001 7.90 0.05 224.03 0.80 8.001 7.90 0.05 234.97 0.80 8.001 7.90 0.05 234.97 0.80 8.001 7.91 0.05 234.97 0.80 8.001 7.93 0.05 250.05 0.80 8.001 7.90 0.05 254.97 0.80 8.001 7.90 0.05 254.97 0.80 8.001 7.90 0.05 254.97 0.80 8.001 7.90 0.05 254.97 0.80 8.001 7.90 0.05 254.97 0.80 8.001 7.90 0.05 254.97 0.80 8.001 7.90 0.05 246.94 0.80 8.001 7.90 0.05	4.664 0.5829	8.001	0.80	210.02	0.05	7.90
7.90 0.05 219.99 0.80 8.001 7.90 0.05 225.03 0.80 8.001 7.90 0.05 234.03 0.80 8.001 7.90 0.05 234.97 0.80 8.001 7.90 0.05 234.98 0.80 8.001 7.90 0.05 234.97 0.80 8.001 7.90 0.05 235.98 0.80 8.001 7.90 0.05 254.97 0.80 8.001 7.90 0.05 254.97 0.80 8.001 7.90 0.05 254.97 0.80 8.001 7.90 0.05 254.97 0.80 8.001 7.90 0.65 254.97 0.80 8.001 7.90 0.65 254.97 0.80 8.001 7.90 0.65 254.97 0.80 8.001 7.90 0.65 274.99 0.80 8.001 7.90 0.65 <td< td=""><td>4.775 0.5968</td><td>8.001</td><td>0.80</td><td>214.99</td><td>0.05</td><td>7.90</td></td<>	4.775 0.5968	8.001	0.80	214.99	0.05	7.90
7.90 0.05 225.03 0.80 6.001 7.90 0.05 230.03 0.80 6.001 7.90 0.05 239.03 0.80 6.001 7.90 0.05 239.98 0.80 6.001 7.91 0.05 239.98 0.80 6.001 7.93 0.05 254.97 0.80 6.001 7.90 0.05 254.97 0.80 6.001 7.90 0.05 254.97 0.80 6.001 7.90 0.05 254.97 0.80 6.001 7.90 0.05 254.97 0.80 6.001 7.90 0.05 254.97 0.80 6.001 7.90 0.05 254.99 0.80 6.001 7.90 0.05 254.99 0.80 6.001 7.90 0.05 274.99 0.80 6.001 7.90 0.05 274.99 0.80 6.001 7.90 0.95 <td< td=""><td>4.887 0.6108</td><td>8.001</td><td>0.80</td><td>219.99</td><td>0.05</td><td>7.90</td></td<>	4.887 0.6108	8.001	0.80	219.99	0.05	7.90
7.90 0.05 220.03 0.80 8.001 7.90 0.05 234.97 0.80 8.001 7.90 0.05 239.88 0.80 8.001 7.91 0.05 245.05 0.80 8.001 7.93 0.05 250.05 0.80 8.001 7.90 0.05 254.97 0.80 8.001 7.90 0.05 254.97 0.80 8.001 7.90 0.05 254.97 0.80 8.001 7.90 0.05 265.04 0.80 8.001 7.90 0.05 265.99 0.80 8.001 7.90 0.05 269.99 0.80 8.001 7.90 0.05 274.99 0.80 8.001 7.90 0.05 274.99 0.80 8.001 7.90 0.05 274.99 0.80 8.001	5.000 0.6249	8.001	0.80	225.03	0.05	7.90
7.90 0.05 23.97 0.80 8.001 7.90 0.05 239.98 0.80 8.001 7.91 0.05 236.05 0.80 8.001 7.90 0.05 250.05 0.80 8.001 7.90 0.05 254.97 0.80 8.001 7.90 0.05 254.97 0.80 8.001 7.90 0.05 254.97 0.80 8.001 7.90 0.05 254.97 0.80 8.001 7.90 0.05 254.97 0.80 8.001 7.90 0.05 254.97 0.80 8.001 7.90 0.05 254.97 0.80 8.001 7.90 0.65 254.97 0.80 8.001 7.90 0.65 274.99 0.80 8.001 7.90 0.65 274.99 0.80 8.001 7.90 0.95 279.99 0.80 8.001	1 5.112 0.6390	8.001	0.80	230.03	0.05	7.90
7.90 0.05 239.98 0.80 8.001 7.91 0.05 246.05 0.80 8.001 7.90 0.05 250.05 0.80 8.001 7.90 0.05 254.97 0.80 8.001 7.90 0.05 254.97 0.80 8.001 7.90 0.05 259.99 0.80 8.001 7.90 0.05 265.04 0.80 8.001 7.90 0.05 264.99 0.80 8.001 7.90 0.05 274.99 0.80 8.001 7.90 0.05 274.99 0.80 8.001	5.223 0.6529	8.001	0.80	234.97	0.05	7.90
7.61 0.05 245.05 0.80 8.001 7.90 0.05 250.05 0.80 8.001 7.90 0.05 254.97 0.80 8.001 7.90 0.05 254.97 0.80 8.001 7.90 0.05 254.97 0.80 8.001 7.90 0.05 265.04 0.80 8.001 7.90 0.05 269.99 0.80 8.001 7.90 0.05 274.99 0.80 8.001 7.90 0.05 274.99 0.80 8.001	5.336 0.6670	8.001	0.80	239.98	0.05	7.90
7.90 0.05 25.05 0.80 8.001 7.90 0.05 254.97 0.80 8.001 7.90 0.65 255.99 0.80 6.001 7.90 0.05 265.04 0.80 6.001 7.90 0.65 265.99 0.80 6.001 7.90 0.65 276.99 0.80 6.001 7.90 0.65 274.99 0.80 6.001 7.90 0.65 274.99 0.80 6.001	5.449 0.6811	8.001	0.80	245.05	0.05	7.91
7.90 0.055 254.97 0.80 8.001 7.90 0.055 259.99 0.80 8.001 7.90 0.65 259.99 0.80 8.001 7.90 0.65 259.99 0.80 8.001 7.90 0.65 259.99 0.80 8.001 7.90 0.65 274.99 0.80 8.001 7.90 0.65 274.99 0.80 8.001	L 5.559 0.6948	8.001	0.80	250.05	0.05	7.90
7.90 0.65 259.99 0.80 8.001 7.90 0.65 265.04 0.80 8.001 7.90 0.65 269.99 0.85 8.001 7.90 0.65 274.99 0.80 8.001 7.90 0.65 274.99 0.80 8.001 7.90 0.65 274.99 0.80 8.001	5.668 0.7085	8.001	0.80	254.97	0.05	7.90
7.90 0.05 285.04 0.80 8.001 7.90 0.05 289.99 0.80 8.001 7.90 0.05 274.99 0.80 8.001 7.90 0.05 274.99 0.80 8.001	5.782 0.7227	8.001	0.80	259.99	0.05	7.90
7.90 0.05 269.99 0.80 8.001 7.90 0.05 274.99 0.80 8.001 7.90 0.05 274.99 0.80 8.001	5.895 0.7369	8.001	0.80	265.04	0.05	7.90
7.90 0.05 274.99 0.80 8.001 7.90 0.05 290.03 0.90 8.001	6.005 0.7506	8.001	0.80	269.99	0.05	7.90
7.90 0.05 290.03 0.90 0.001	6.116 0.7644	8.001	0.80	274.99	0.05	7.90
100.8	6.229 0.7786	8.001	0.90	280.03	0.05	7.90
7.90 0.05 285.05 0.80 8.001	6.341 0.7926	8.001	0.80	285.05	0.05	7.90
7.91 0.05 289.75 0.80 8.001	6.445 0.8056	8.001	0.80	289.75	0.05	7.91
7.90 0.05 295.01 0.80 8.000		8.000	0.80	295.01	0.05	7.90
7.90 0.05 299.94 0.80 8.001	6.553 0.8191		0.80	299.94	0.05	7.90
7.90 0.05 304.99 0.80 8.001	6.553 0.8191 6.665 0.8330	8.001				7.90
7.90 0.05 310.05 0.80 8.001	0 6.553 0.8191 6.665 0.8330 6.777 0.8471	8.001 8.001	0.80	304.99	0.05	
7.90 0.005 239.94 0.80 8.001 7.90 0.05 304.99 0.80 8.001 7.90 0.05 304.99 0.90 8.001 7.90 0.05 310.05 0.90 8.001		8.000	0.80	299.94	0.05	7.90

10.3.4 Calibration protocol dir₄

Date Dotum	Head of the calibration laboratory Leiter des Kolibrier/aboratoriums	Person in charge Bearbeiter	
20.06.2019	D. Jostomum	Solut	
	Dipl. Phys. Dieter Westermann	Kai Schuster, B. Eng.	

			1922033
2/6			D-K-
eite			15140-01-00
			06/2019
Calibration object Kalibriergegenstand	Wind Vane		
Calibration procedure Kolibrierverfahren	IEC 61400-12-1:2017		
Place of calibration Ort der Kalibrierung	Wind tunnel of Deutsche Wind	Guard WindTunnel Services Gn	nbH, Varel
Test conditions	wind tunnel area	10000 cm ²	
messeeungungen	anemometer frontal area	200 cm ²	
	diameter of mounting pipe	33.7 mm	
	blockage ratio 1)	0.020 [-]	
	software version	P_8.0.03	
	$^{1)}\mathrm{Due}$ to the special construction of th	e test section no blockage correction is	necessary.
Ambient conditions	air temperature	25.9 °C±0.1 °C	
Umgebungsbeaingungen	air pressure	1009.8 hPa ± 0.3 hPa	
	relative air humidity	63.0 % ± 2.0 %	
Measurement uncertainty Messunsicherheit	The expanded uncertainty assi multiplying the standard uncer determined in accordance with within the assigned range of var The reference flow speed meas (Physikalisch-Technische Bund by using a PTB owned and calit Uncertainty 0.2 %, <i>i=2</i>)	gned to the measurement resul tainty by the coverage factor is to DAkkS-DKD-3. The value of the lues with a probability of 95%. surement is traceable to the Ge esanstalt] standard for flow spe rrated Laser Doppler Anemome	ts is obtained by 2. It has been e measurand lies rman NMI ed. It is realized ter (Standard
Additional remarks			
Revision	0		

3/6						D-K- 15140-01-00
						06/2019
bration result rierergebnis (1/3	t (1/3)					
Reference	Reference	Reference	Reference	Test item	Test item	Test Item
Air velocity	Unc	Yaw angle	Unc	Source	Wiper	Ratio
m/s	m/s	deg	deg	v	v	
7.90	0.05	5.01	0.80	8.000	0.116	0.0145
7.90	0.05	10.00	0.80	8.000	0.226	0.0283
7.90	0.05	14.99	0.80	8.000	0.338	0.0422
7.90	0.05	19.97	0.80	8.000	0.450	0.0562
7.90	0.05	24.61	0.80	8.000	0.551	0.0689
7.90	0.05	30.03	0.80	8.001	0.672	0.0840
7.90	0.05	35.08	0.80	8.001	0.783	0.0979
7.90	0.05	40.06	0.80	8.001	0.894	0.1118
7.90	0.05	45.12	0.80	8.001	1.008	0.1260
7.90	0.05	50.12	0.80	8.001	1.121	0.1401
7.90	0.05	55.14	0.80	8.001	1.233	0.1541
7.90	0.05	60.13	0.80	8.001	1.344	0.1679
7.90	0.05	65.03	0.80	8.001	1.453	0.1816
7.90	0.05	69.98	0.80	8.001	1.562	0.1952
7.90	0.05	75.02	0.80	8.001	1.674	0.2093
7.90	0.05	80.03	0.80	8.001	1.786	0.2233
7.91	0.05	85.00	0.80	8.001	1.896	0.2370
7.90	0.05	89.94	0.80	8.001	2.007	0.2508
7.90	0.05	94.94	0.80	8.001	2.119	0.2648
7.90	0.05	99.92	0.80	8.001	2.230	0.2787
7.91	0.05	104.94	0.80	8.001	2.339	0.2924
7.90	0.05	109.95	0.80	8.001	2.451	0.3064
7.90	0.05	114.98	0.80	8.001	2.564	0.3205
7.90	0.05	120.02	0.80	8.001	2.675	0.3343
7.90	0.05	124.99	0.80	8.001	2.785	0.3481
7.90	0.05	129.90	0.80	8.001	2.895	0.3618
7.90	0.05	134.95	0.80	8.001	3.006	0.3757
7.90	0.05	139.97	0.80	8.001	3.119	0.3898
7.90	0.05	144.91	0.80	8.001	3.228	0.4035
7.90	0.05	149.91	0.80	8.001	3.340	0.4174
7.90	0.05	154.96	0.80	8.001	3.452	0.4314
	Current					EUTECHE

Page 4 / 6 Seite						192203 D-K- 15140-01 06/201
Calibration result	(2/3)					
Reference	Reference	Reference	Reference	Test item	Test item	Test item
Air velocity	Unc	Yaw angle	Unc	Source	Wiper	Ratio
m/s	m/s	deg	deg	v	v	
7.89	0.05	160.01	0.80	8.001	3.563	0.4454
7.90	0.05	165.00	0.80	8.001	3.675	0.4593
7.90	0.05	170.01	0.80	8.001	3.786	0.4732
7.90	0.05	175.02	0.80	8.001	3.898	0.4872
7.90	0.05	179.99	0.80	8.001	4.010	0.5012
7.90	0.05	185.01	0.80	8.001	4.122	0.5152
7.90	0.05	189.98	0.80	8.001	4.232	0.5290
7.90	0.05	194.95	0.80	8.001	4.343	0.5428
7.90	0.05	199.98	0.80	8.001	4.455	0.5568
7.91	0.05	205.01	0.80	8.001	4.569	0.5710
7.90	0.05	210.05	0.80	8.001	4.682	0.5851
7.90	0.05	215.02	0.80	8.001	4.793	0.5990
7.90	0.05	219.96	0.80	8.001	4.903	0.6128
7.90	0.05	224.98	0.80	8.001	5.015	0.6268
7.91	0.05	230.02	0.80	8.001	5.128	0.6409
7.91	0.05	234.96	0.80	8.001	5.239	0.6548
7.90	0.05	239.94	0.80	8.001	5.350	0.6687
7.90	0.05	245.03	0.80	8.001	5.463	0.6828
7.90	0.05	250.05	0.80	8.001	5.572	0.6964
7.90	0.05	255.00	0.80	8.001	5.682	0.7102
7.90	0.05	259.99	0.80	8.000	5.795	0.7243
7.90	0.05	265.03	0.80	8.000	5.907	0.7384
7.90	0.05	270.01	0.80	8.000	6.019	0.7524
7.90	0.05	274.99	0.80	8.000	6.129	0.7662
7.90	0.05	280.08	0.80	8.000	6.242	0.7803
7.90	0.05	285.13	0.80	8.000	6.356	0.7945
7.90	0.05	290.05	0.80	8.000	6.458	0.8073
7.90	0.05	295.01	0.80	8.000	6.564	0.8206
7.90	0.05	299.96	0.80	8.000	6.676	0.8345
7.90	0.05	304.91	0.80	8.000	6.786	0.8483
7.90	0.05	309.89	0.80	8.000	6.898	0.8523
Deutsche Wind	Guard		-		D	EUTSCHE

Massachusetts Clean Energy Center

1922033 D-K-15140-01-00 06/2019

WINDGUARD

ents -

10.4 Air temperature and humidity sensor

10.4.1 Air temperature and humidity sensor 1

Z M K	Zentrum f &	ür Messen ANALYTIK	und Kalibrieren K GmbH	
akkreditiert durch	die / accredited	by the	of the second se	
Deutsche A	kkreditierur	ngsstelle Gm	ibH lacuna ((DAkk	S sutsche iverbitierungsstable
als Kalibrierlabora	torium im / as cali	bration laboratory	in the	1-15186-01-00
Deutschen K	alibrierdien	st Di	(D	14-0177
				D-K-
Kalibrierschein Calibration certificate	Zwe	ltechrif	Kalibrierzeichen	2017-03
	Ans 6 4 44		u.	
Gegenstand Object Hersteller	Temperatur-/Feu Galltec + mela	chtefühler	Dieser Kalibrierschein dokumen führung auf nationale Normale der Einheiten in Übereinstimn Internationalen Einheitensystem Die Dakks ist Unterzeichner des	tiert die Rück- zur Darstellung hung mit dem {SI}. multilateralen
Monufacturer	KDC4 S/R ME		Übereinkommen der European o	o-operation for
Тур Туре	KPC1.5/6-ME		tory Accreditation (EA) und der Intern tory Accreditation Cooperation	(ILAC) zur ge-
Fabrikat/Serlen-Nr. Serial number	176894		genseitigen Anerkennung der Kal Für die Einhaltung einer angeme: Wiederholung der Kalibrierung is worantwestlich	lbrierscheine. Isenen Frist zur st der Benutzer
Auftraggeber Customer	UL International (Ebertstraße 96 26382 Wilhelshav	GmbH ven	This calibration certificate d traceability to national standard; the units of measurement acc international System of Units (SI). The DAkkS is signatory to ti	scuments the ; which realize arding to the multilateral
Auftragsnummer		37100001895	agreements of the European co	-operation for
Anzahl der Seiten des H Number of pages of the certi	Calibrierscheines	3	Laboratory Accreditation Coopen the mutual recognition of calibr	ation (ILAC) for ation certifica-
Datum der Kalibrierung Date of colibration	t –	03.03.2017	tes. The user is obliged to have the broted at appropriate intervals.	object recali-
Dieser Kalibrierschein darf e sowohl der Deutschen Akkre keine Gültigkeit. This collbration certificate m and the issuing laboratory. Ci	ur vollständig und unverä ditierungsstelle GmbH als a ay not be reproduced other aföration certificates witho	ndert weiterverbreitet wen such des ausstellenden Kall than in full except with the ut signoture are not valid.	den. Auszüge oder Änderungen bedürfen de brierlaboratoriunts. Kalibrierscheine ohne Unt permission of both the Deutsche Akkreditieru	r Genehmigung erschrift haben ngsstelle Grabti
Datum Date	Stelly. Leiter des Kalibrier Deputy Head of the calibr	aboratoriums ation laboratory	Bearbeiter Person in charge	
	(IIIA		Laure	
06.03.2017	Frau pr. Jehnert		Frau Lange	
Kalibrierlaboratorium f thermodynamische um Calibration laboratory foi thermodynamical and an Ortsteil Wolfen, P-D Chemi Teleton (03494) 69730 + FA	ür Länge, elektrische d analytische Messgr length, electrical, met lalytical measuring que Park Bitterfeld-Wolfen, A X (03494) 697334 - emai	r, mechanische, ößen chanical, antities weal A, Filmstraße Nr.7, C linfo@zmk-wolfen.de	DOS-zentificient RegN	nach DIN EN ISO S001 hr: 084774 GM

Seite 2 Page		D+) 15186-1 2017
Kalibriergegenstand		
Temperatur-/Feuchtefühler		
	Typ: Hersteller: Serien-Nr.; Messbereich: Ausgangsspannung: Kalibrierpunkte:	KPC1:St9-ME Galitoc + mela 178804 rel. Feuchts: (0100) % // Temp.: (-30 70) *C (01) V (3050/70) % bel 20 *C (-10/10/40) *C
Normale		
Taupunktspiegel mit Anzeigegerät	Typ: Hersteller: Nr.: Kalibrierung:	D-2-XR // HYGRO-M3 General Eastern GD14/G004 D-K-15186-01
Platin-Widerstandsthermomete	rTyp: IdentNr.: Kalibrierung:	Pt 100 GD14/G045 D-K-15186-01
DC-Temperaturmessbrücke	Typ: IdentNr.: Kalibrierung:	MKT 50 GD14/G038 D-K-15186-01
Multifunktionskalibrator:	Typ: Nr.: Hersteller: Kalibrierung:	MC 5 GD14/G034 Beamex D-K-15186-01
Kalibrierverfahren		
Die Kalibrierung erfolgt im dire	kten Veraleich der Anze	ige des Prüflings mit der Temperatur und der relative

Messbedingungen

Der Profiling befand sich während der Kalibrierung innerhalb eines thermostatisierten Volumens in der Klimakammer im direkten Feuchtluftstrom. Die Messung wurde erst nach Einstellung stabiler Temperaturen und reuchtwerde vorgenommen, d.h. wem die Anzuge des Pröfilings und die zur Berechnung der refativen Feuchte (Bezugswert) notwendigen Parameter keine systematischen Anderungen mehr erkennen ließen. Die in der Tabelle angegehenen Werte sind Mittlewert aus Mehrfahremessungen Der Messunformer wurde mit einer Bertriebsspannung von 24 V versorgt. Die der refativen Feuchte bzw. Lufttemperatur proprionale Ausgangsspannung (V bis 1 V entsprechend 0 % bis 100 % bzw. -30 °C bis 70 °C) wurde mit dem Multifunktionskalibrator gemessen.

Umgebungsbedingungen

Temperatur : (23,0 ± 5,0) °C rel. Feuchte : (50 ± 20) %

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		D-K- 15186-01-00
		2017-02

Messergebnisse Feuchtemessung

Seite 3 Page

Temperatur des Feucht- luftstromes	relative Feuchte Bezugswert	Ausgangsspannung Messumformer	relative Feuchte Prüfling *	Anzeigekorrektion	Messunsicherheit
in °C	in %	in V	in %	in %	in %
20	27,5	0,27694	27,7	-0,2	0.42
20	49,1	0,48429	48,4	0,7	0,62
20	69,6	0,68988	69,0	0,6	0,92

* die relative Feuchte wurde aus der Ausgangsspannung berechnet

Die relative Feuchte ergibt sich aus der Beziehung:

rel. Feuchte = rel. Feuchte Prüfling + Anzeigekorrektion

Temperaturmessung

Temperatur Normal	Ausgangsspannung Messumformer	Temperatur Prüfling *	Anzeigekorrektion	Messunsicherheit
in °C	in V	in °C	in K	in K
-10,424	0,19474	-10,53	0,11	0.15
9,978	0,39904	9,90	0,08	0.15
20,065	0,50219	20,22	-0,15	0,15
39,935	0,69950	39,95	-0,01	0,15

* die Temperatur wurde aus der Ausgangsspannung berechnet

Die Temperatur ergibt sich aus der Beziehung:

Temperatur = Temperatur Prüfling + Anzeigekorrektion

Messunsicherheit

Angegeben ist die erweiterte Messunsicherheit, die sich aus der Standardmessunsicherheit durch Multiplikation mit dem Erweiterungsfaktor k = 2 ergibt. Sie wurde gemäß DAkkS-DKD-3 ermitteit. Der Wert der Messgröße liegt mit einer Wahrscheinlichkeit von annähernd 95% im zugeordneten Werteintervall.

Hinweis

Die Deutsche Akkreditierungsstelle GmbH ist Unterzeichner der multilateralen Übereinkommen der European co-operation for Accreditation (EA) und der International Laboratory Accreditation Cooperation (LIAC) zur gegeneetigen Ansrehennung der Kalbinerscheine. Die weiteren Unterzeichner Innerhalts und außertabis Europes sind den Internetselten von EA (<u>www.european-accreditation.org</u>) und ILAC (<u>www.ilac.org</u>) zu entrehmen.

Die Werte gelten für den Zustand des Kalibriergegenstandes zum Zeitpunkt der Kalibrierung.

10.4.2 Air temperature and humidity sensor 2

Z	Zentrum fü & A	r Messen u ANALYTIK	ınd Kalibrieren GmbH	
akkreditiert durc	h die / accredited by	the	19 A	
Deutsche A	kkreditierung	sstelle Gmb	H Hackers ((DAkk	S utsche
als Kalibrierlabora	torium im / as calibr	ation laboratory in	the	-15186-01-40
Deutschen H	Calibrierdiens	DK	D	14-1215
Kalibrierschein			Kalibrierzeichen	D-K- 15186-01-00
Calibration certificate			Calibration mark	2017-11
Gegenstand Object	Temperatur-/Feuch	tefühler	Dieser Kalibrierschein dokumen führung auf nationale Normale : der Einheiten in Übereinstimm	tiert die Rück- zur Darstellung nung mit dem
Hersteller Manufacturer	Galitec + mela		Internationalen Einheitensystem (SI). Die DAkkS ist Unterzeichner der multila Übereinkommen der European co opere	
Тур Туре	KPC1.S/6-ME		Accreditation (EA) und der Intern tory Accreditation Cooperation genseitigen Aperkennung der Kall	ational Labora- (ILAC) z.r ge-
Fabrikat/Serien-Nr. Serial number	183591		Für die Einhaltung einer angemes Wiederholung der Kallbrierung is	senen Frist zur t der Benutzer
Auftraggeber Customer	UL International Gr Ebertstraße 96 26382 Wilhelmshav	nbH ren	verantwortuch. This calibration certificate di traceability to national standards the units of measurement acc International System of Units (SI). The DAkkS is signatory to th	ocuments the s, which realize ording to the
Auftragsnummer Order No.		3710002980	agreements of the European co Accreditation (EA) and of the	operation for Internctional
Anzahl der Seiten des Number of pages of the cert	Kalibrierscheines ificate	3	Laboratory Accreditation Coopere the mutual recognition of calibr	ation (ILAC) for ation certifica-
Datum der Kalibrierun Date of colibration	В	24.11.2017	tes. The user is obliged to have the brated at appropriate intervals.	object recali-
Dieser Kalibrierschein darf sowohl der Deutschen Akkr keine Gültigkeit. This calibration certificate n and the issuing laboratory. (nur vollständig und unverändi editierungsstelle GmbH als au nay not be reproduced other th Calibration certificates without.	ert weiterverbreitet werde h des ausstellenden Kalibr an in full except with the p signature are not valid.	n. Auszüge oder Änderungen bedürfen de erlaboratoriums. Kalibrierscheine ohne Unt ermission of both the Deutsche Akkreditieru	r Genehmigung erschrift kaben ngsstelle GmbH
Datum Date	Stelly. Leiter des Kalibrierfab Deputy Head of the colibrati	oratoriums on laboratory	Bearbeiter Person in chorge	
27.11.2017	Frau Dr Jebnect		Frau Lange	
Kalibrierlaboratorium thermodynamische ur Calibration laboratory fo thermodynamical and a Drtsteil Wolfen, P-D Chem Elefon (13404) 5970 - E	für Länge, elektrische, i danalytische Messgröi br length, electrical, mech nalytical measuring quan iePark Bitterfeld-Wolfen, Are X (0240) 697334	nechanische, Sen anical, ities al A, Filmstraße Nr.7, 06	DQS-zerifizier RegN	nach DIN EN ISO BOOT

Seite 2 Page		D-K- 15186-01- 2017-11
Kalibriergegenstand		L
Temperatur-/Feuchtefühler		
	Typ: Hersteller: Serien-Nr.: Messbereich: Ausgangsspannung: Kalibrierpunkte:	KPC1.S/6-ME Galitoc + mela 185501 rel. Feuchte: (0100) % // Temp.: (-30 70) *C (01) V (30/50/70) % bei 20 *C (-1010/40) *C
Normale		
Taupunktspiegel mit Anzeigegerät	Typ: Hersteller: Nr.: Kalibrierung:	473-SHX MBW Calibration AG GD14/G057 SCS0125
Platin-Widerstandsthermome	lerTyp: IdentNr.: Kalibrierung:	Pt 100 GD14/G007 D-K-15186-01
DC-Temperaturmessbrücke	Typ: IdentNr.: Kalibrierung:	MKT 50 GD14/G035 D-K-15186-01
Multifunktionskalibrator:		
	Typ: Nr.: Hersteller: Kalibrierung:	MC 5 GD14/G034 Beamex D-K-15186-01
Kalibrierverfahren		
Die Kalibrierung erfolgt im dire Feuchte (Bezugswert), welche	ekten Vergleich der Anze e aus der Taupunkttemp	eige des Prüflings mit der Temperatur und der relativen eratur, der Gastemperatur und dem Luftdruck berechnet

Massachusetts Clean Energy Center

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Messergebnisse Feuchtemessung

Temperatur des Feucht- luftstromes	relative Feuchte Bezugswert	Ausgangsspannung Messumformer	relative Feuchte Prüfling *	Anzeigekorrektion	Messursicherheit
in °C	in %	in V	in %	in %	in %
20	28,4	0,30129	30,1	-1.7	0.42
20	49,3	0,50262	50,3	-1.0	0.62
20	69.8	0.69169	60.2	0.6	0.00

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D-K-15186-01-00 2017-11

* die relative Feuchte wurde aus der Ausgangsspannung berechnet

Die relative Feuchte ergibt sich aus der Beziehung:

rel. Feuchte = rel. Feuchte Prüfling + Anzeigekorrektion

Temperaturmessung

Temperatur Normal	Ausgangsspannung Messumformer	Temperatur Prüfling *	Anzeigekorrektion	Messunsicherheit
in °C	in V	in °C	in K	in K
-9,861	0,19998	-10,00	0,14	0.15
9,851	0,39813	9,81	0.04	0.15
19,962	0,49898	19,90	0.06	0.15
40,063	0,70075	40,07	-0,01	0,15

* die Temperatur wurde aus der Ausgangsspannung berechnet

Die Temperatur ergibt sich aus der Beziehung:

Temperatur = Temperatur Prüfling + Anzeigekorrektion

Messunsicherheit

Angegeben ist die erweiterte Messunsicherheit, die sich aus der Standardmessunsicherheit durch Multiplikation mit dem Erweiterungstaktor /# 2 ergibt. Sie wurde gemäß DAkkS-DKD-3 ermittelt. Der Wert der Messgröße liegt mit einer Wehrscheinlichkeit von annäherte dir Sin zu zugedraten Wertenitervall.

Hinweis

Die Deutsche Akkreditierungsstelle GmbH ist Unterzeichner der multilateralen Übereinkommen der European co-operation for Accreditation (EA) und der International Laboratory Accreditation Cooperation (ILAC; zur gegenestitigen Anerkennung der Kaltbinrescheine. Die weiteren Unterzichner innerhalt und außenhalb Europas sind den Internetseiten von EA (<u>www.european-accreditation corg</u>) und ILAC (<u>www.ilac.org</u>) zu entnehmen.

Die Werte gelten für den Zustand des Kalibriergegenstandes zum Zeitpunkt der Kalibrierung.

10.5 Air pressure sensor

10.5.1 Air pressure sensor 1

1 (1) Certificate report no. H47-17170021

CALIBRATION CERTIFICATE

Instrument Serial number Manufacturer Calibration date

PTB110 Barometer N1720456 Vaisala Oyj, Finland 26th April 2017

This instrument has been calibrated against a Vaisala PTB220 factory working standard. The Vaisala PTB220 is traceable to the National Institute of Standards and Technology (NIST, USA) via Vaisala Measurement Standards Laboratory (MSL). Vaisala MSL has been accredited by FINAS according to ISO/IEC 17025 standard.

At the time of shipment, the instrument described above was within its operating specifications.

Calibration results

Reference pressure hPa	Calculated pressure hPa	Observed voltage Vdc	Correction* hPa	Uncertainty** hPa
809.9	809.9	0.191	0.0	± 0.15
900.2	900.2	1.927	0.0	± 0.15
1000.3	1000.3	3.852	0.0	± 0.15
1060.0	1060.0	5.000	0.0	± 0.15

Equipment used in calibration Type Ser HP34970A EM PTB220 PA

Serial number EM 14611 PA 14019 Calibration date 2016-10-24 2016-08-02

Temperature: 22 ± 2 °C

Certificate number 1250-307079098 K008-Z02342

Ambient conditions Humidity: 31 ± 5 %RH

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Pressure: 994 ± 20 hPa

Technician

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10.5.2 Air pressure sensor 2

1 (1) Certificate report no. H47-17170019

CALIBRATION CERTIFICATE

Instrument Serial number Manufacturer Calibration date

PTB110 Barometer N1720454 Vaisala Oyj, Finland 26th April 2017

This instrument has been calibrated against a Vaisala PTB220 factory working standard. The Vaisala PTB220 is traceable to the National Institute of Standards and Technology (NIST, USA) via Vaisala Measurement Standards Laboratory (MSL). Vaisala MSL has been accredited by FINAS according to ISO/IEC 17025 standard.

At the time of shipment, the instrument described above was within its operating specifications.

Calibration results

Reference pressure hPa	Calculated pressure hPa	Observed voltage Vdc	Correction* hPa	Uncertainty** hPa
809.9	809.9	0.191	0.0	± 0.15
900.2	900.2	1.927	0.0	± 0.15
1000.3	1000.3	3.852	0.0	± 0.15
1060.0	1060.0	5.000	0.0	± 0.15

Pressure: 994 ± 20 hPa

*To obtain the true pressure, add the correction to the barometer reading. Interpolated corrections may be used at intermediate readings of the scale of the barometer. **The calibration uncertainty given at 95 % confidence level, k = 2

Equipment used in calibration

Type	Serial number	Calibration date	Certificate number
HP34970A	EM 14611	2016-10-24	1250-307079098
PTB220	PA 14019	2016-08-02	K008-Z02342

Ambient conditions Humidity: 31 ± 5 %RH

Temperature: 22 ± 2 °C

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