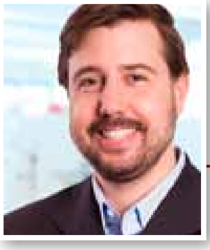
# Influence of Varying Temperature and Pressure on Calibration of Anemometer



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## Introduction

In the recent industry scenario, we have moved towards reverse bidding process from Feed-in-Tariff (FiT) based Power Purchase Agreements (PPAs), which is quite challenging for the Independent Power Producers (IPPs) in terms of achieving good Internal Rate of Returns, for the turbine manufacturers to match with their competitors in terms of pricing as well as the lenders to mitigate risk in lending.

It is obvious that the Annual Energy Production (AEP) figures taken into the financial viability model plays a vital role, which depends on various factors and uncertainties. The most contributing and crucial parameter that directly influences the AEP at gross level is the wind speed measured and taken into consideration and the measurement setup indirectly influences the AEP estimations at different probability levels from 50% to 99%. Calibration of the anemometers used in the measurements, increases the confidence and reliability of the AEP estimation.

Anemometer calibration is crucial and helps to determine the quality of measurement campaign. Generally, it takes place in the wind tunnel with the constant, prevailing air temperature and atmospheric pressure conditions as recommended in IEC 61400-12-1 standard[1]. However, the performance of the anemometer's behavior can highly depend on site specific environmental conditions and hence it is recommended to select the appropriate anemometer for the particular measurement campaign. Furthermore, it is important to have a measure of the environmental influence on the wind sensor and thereby on the site assessment and the wind turbine control.

In the latest IEC 61400-12-1 standard[1], there are different influence parameters which have to be investigated during the anemometer classification. The air density is a function of air temperature and air pressure. To investigate the influence of a variation in air density, either the air temperature or the pressure can be altered. It is difficult to distinguish between the influence of changing air temperature and density if temperature variation is used to adjust the air density during the calibration. If both parameters, air temperature and air pressure, can be varied independently, the clear results will be obtained.

In standard wind tunnels air temperature and pressure can usually not be set deliberately. Therefore, the impact of these environmental conditions cannot be estimated reliably. A special, closed-return research wind tunnel has been developed by Deutsche WindGuard with the ability to vary the wind tunnel local pressure and temperature independently. The measurement results presented in this article are part of the report "VT180259_01_Rev0, Anemometer calibration at different air temperatures and air pressures."[2]

## Technical Description of the Variable Air Density Wind Tunnel

The variable air density wind tunnel has a closed-return design, a closed test section and delivers a homogeneous flow with low turbulence (<0.5 %). It is designed for investigation of anemometers at different ambient pressures and temperatures. The design criteria were laid out in line with the requirements of IEC 61400-12-11. Based on the design criteria, the novel wind tunnel with a contraction ratio of 3.3:1, a 0.8 m long test-section, and a cross-sectional area of 0.5 m x 0.5 m was chosen and implemented at our headquarters as shown in figure 1 and 2. This provides an acceptable blockage ratio for the intended anemometer testing at different air densities.

In order to achieve a high-quality flow, there is a settling chamber before the nozzle that consists of honeycombs and screens to improve the flow quality and reduce the turbulence level. The wind tunnel is constructed with hermetically sealed sheet metal which ensures the reliable variation of internal pressure. Furthermore, the whole wind tunnel is placed in an insulated and temperature-controlled chamber.

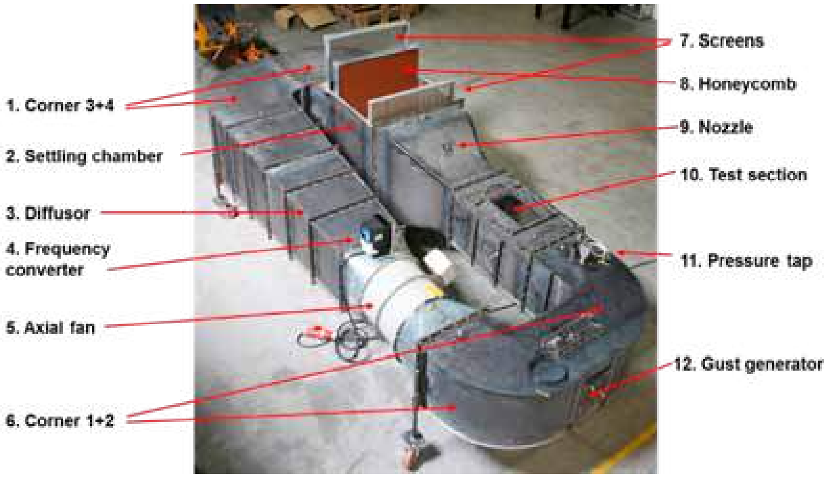


**Figure 1:**
*Photo of the Variable Air Density Wind Tunnel during the Installation*

**Figure 2:**
*Photo of the Variable Air Density Wind Tunnel of Windguard Wind Tunnel Services*

*(Source: VT180259_01_Rev02)*

Based on our experience in designing and building wind tunnels, well proven values of diffuser angles, contraction ratios, components and known pressure drop coefficients were utilized in the design calculations. An appropriately sized fan unit was chosen to compensate the calculated pressure loss in the wind tunnel system and produce the desired wind speed at the test section.

## Calibration Procedure

To reduce the measurement uncertainties, first the anemometer has to be calibrated at normal ambient conditions in one of WindGuard's four accredited wind tunnels. Subsequently a measurement in the variable air density wind tunnel is performed at similar conditions (temperature and pressure) prevailing during the first measurement. From the measurements the transfer factor of the anemometer is determined.

For the measurements described in this paper, the following calibration procedure is used. While calibrating the anemometer in the variable air density wind tunnel, 4 m/s to 15.5 m/s wind speed range is considered.

In order to decrease type 'A' uncertainty, the minimum duration of the sampling interval 30s is considered. For each calibration run a linear regression analysis is performed, resulting in a calibration function with slope and offset for one particular air temperature and pressure respectively.

## Calibration Procedure for Varying Air Temperatures

The air pressure is kept constant and the air temperature is decreased down to -20°C and increased by 5°C untill the maximum of 40°C. At each temperature step the calibration is performed.

## Calibration Procedure for Varying Air Pressures

During the calibrations at varying air pressures the air temperature is kept constant at 10°C and the air pressure is increased by 50 hPa from 700 hPa up to 1100 hPa. At each pressure step the calibration is done.

## Sample Results

Two similar cup anemometers with a frequency output from two different manufacturers were tested and both anemometers were equipped with roller bearings. In order to compare the performance, the ratio (k) of measured wind speed (if the anemometer is not calibrated for different air temperature and air pressure) and the reference wind speed is taken into account and expressed as:

$$k_{(T,p)} = \frac{f_{(T,p)} / v_{(T,p)}}{f_{(20°C,1000\ hPa)} / v_{(20°C,1000\ hPa)}}$$

where:

$f_{(T,p)}$ : Frequency output at wind speed $v_{(T,p)}$ for a certain air temperature $T$ and pressure p.

$f_{(20°C,1000\ hPa)}$ : Frequency output at wind speed $v_{(20°C,1000\ hPa)}$ for measurements at 20°C air temperature and $1000\ hPa$ air pressure.

## Calibration Results for Varying Air Temperatures

The ratio k for the anemometers A & B calculated and normalized to the results at 20°C is illustrated in figure 3 for varying temperatures. Anemometer A has a decreasing ratio for decreasing temperatures whereas anemometer B has the opposite characteristic. Furthermore, the influence of varying the air temperature is stronger at lower wind speeds.

## Calibration Results for Varying Air Pressures/Air Densities

The influence of varying air pressures/air densities is illustrated in the figure 4. The different air densities are obtained by varying the air pressure at a constant air temperature of 10°C. The ratio

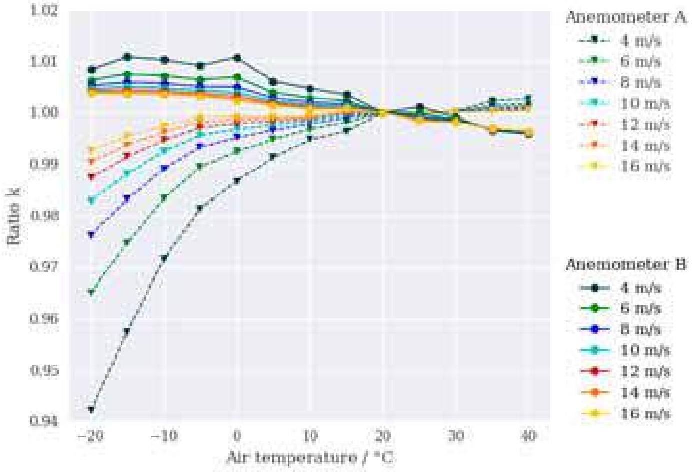


**Figure 3:**
*Ratio* k *for Anemometer A and B at Varying Air Temperatures and Wind Speeds and at Constant Air Pressure*
*(Source: VT180259_01_Rev0[2])*

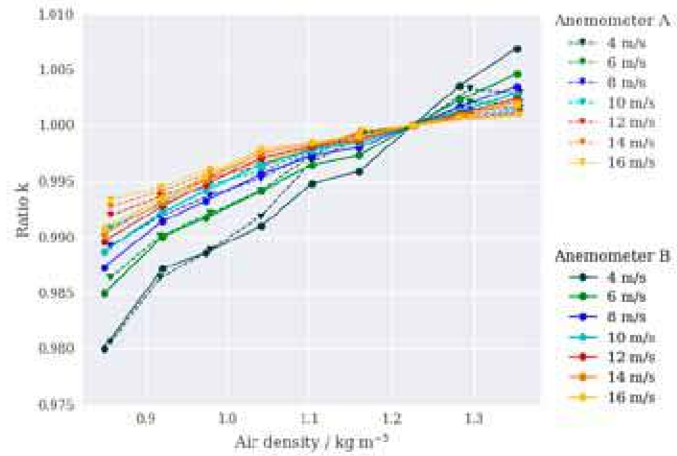


**Figure 4:**
*Ratio* k *for Anemometer A and B at Varying Air Density and Wind Speeds and at Constant Air Temperature*
*(Source: VT180259_01_Rev02)*

k for the anemometers A & B is calculated and normalized to the results at 1000 hPa and corresponding to an air density of approximately 1.23 kg/m³. The influence of varying densities for both anemometers is similar. Both anemometers have a decreasing ratio for decreasing pressure. The influence is again stronger for lower wind speeds.

## Conclusion

The above results show the influences on the anemometer's performance at varying environmental conditions, especially at low temperatures. The opposing characteristics of both anemometer types demonstrate that a change in air temperature can have other effects than just an increase in bearing friction. Therefore, it is necessary to perform tests in which the whole anemometer is exposed to different temperatures.

Moreover, as the air density is dependent on air temperature and air pressure, the influence of the air density and air temperature on cup anemometer measurements can be very different. None of these aspects are covered in IEC 61400-12-11.

If cup anemometers are used in cold climate regions or in higher altitudes, a standard calibration can lead to an under or over estimation of the wind speed. The magnitude may be in the order of several percent in wind speed, which is an even greater deviation in wind power. Also, the use of anemometers for the wind turbine control in these regions may result in a delayed start of power production, especially as the influence of air pressure and temperature is the highest for low wind speeds.

The correction algorithm may be developed considering air pressure, air temperature and wind speed. This correction function has to be individually developed for each anemometer type. Recent developments in the industry have unveiled anemometers that have facilities to be programmed with correction algorithms.

## References


1. IEC 61400-12-1, Edition 2.0, Wind energy generation systems – Part 12-1: Power performance measurements of electricity producing wind turbines, IEC TC/SC 88, 2017
2. VT180259_01_Rev0, Anemometer calibration at different air temperatures and air pressures". Busche Peter et al. 2018. https://www.windkanalzentrum.de/veroeffentlichungen.html?file=files/cto_layout/img/unternehmen/Ver%C3%B6ffentlichungen/Anemometer%20calibration%20at%20different%20air%20temperatures%20and%20air%20pressures_2018.pdf


Snippet

### ReNew Power, Greenko Keen to Buy out Chandigarh Discom

Two of India's largest green energy firms, ReNew Power Ventures Pvt. Ltd and Greenko Energy Holdings, are among 10 companies that have shown an interest in buying out Chandigarh's electricity distribution company (discom). Their interest in the discom business comes against the backdrop of their strategy to capture value across the electricity business chain. The others who have bought the request for proposals (RFP) document made available from 10 November for the Chandigarh discom are Tata Power, CESC Ltd, Torrent Power, Adani Group, NTPC Ltd, GMR Group, India Power Corporation Ltd, and Sterlite Power. These firms have been attracted by the robust per capita power consumption of these discoms. The Chandigarh discom sale also marks the start of India's efforts to privatise the electricity discoms of its Union territories as part of its next generation power sector reforms.

*(Source: Mint, 24 Nov 2020)*