

## Impact of temperature, pressure and humidity on wind energy evaluations

### 1) Standard for wind energy measurement

The reference standard IEC 61400-121 for wind energy measurement states, that a measurement of temperature and air pressure is required. Furthermore the reference standard IEC 61400-121 recommends that air humidity shall be measured in high temperatures.

### 2) Impact of air temperature, pressure and humidity on wind energy earnings

Temperature, air pressure and air humidity have an important influence on wind energy.

- Wind energy is proportional to air density. According to Betz' law windpower is:

$$P_0 = 1/2 \rho * A * v^3$$

- Air density  $\rho$  itself depends on pressure  $P$  and temperature  $T$ , according to formula:

$$\rho = P / (R * T)$$

$\rho$  = density of air in kg/m<sup>3</sup> /  $P$  = air pressure (in hPa) /  $T$  = temperature in Kelvin /  $R$  = gas constant.

#### Summary:

Normal fluctuations of temperature and pressure may induce a variation of up to 10% of wind energy earnings.

### 3) Impact of temperature

A 10°C difference in temperature degrees will generate a difference of approx. 4 % in air density and therefore in the wind energy earnings. Between -10°C and +30°C the discrepancy amounts to more than 15% (refer to schedule on page 2).

### 4) Impact of pressure

Depending on the weather conditions air pressure fluctuates between 980 and 1050 hPa, (this equals +/- 4%).

It is crucial to take altitude into account when measuring air pressure and wind energy, as air pressure drops quickly in higher altitude levels. At ground level with about 1 hPa every 8 meter, resulting in a 10% lower air pressure (wind energy) at sea level compared to air pressure in altitude of 800m.

## 5) Impact of humidity

The impact of humidity is characterised by higher temperatures.

The following schedule shows the air weight in relation to temperature and humidity:

### Density of air at standard atmospheric pressure

Temperature Celsius	Temperature Fahrenheit	Density, i.e.mass of dry air per kg/m <sup>3</sup>	Max. water content per kg/m <sup>3</sup>
-20	-4	1,395	
-15	5	1,368	
-10	14	1,342	
-5	23	1,317	
0	32	1,292	0,005
5	41	1,269	0,007
10	50	1,247	0,009
15	59	1,225 *)	0,013
20	68	1,204	0,017
25	77	1,184	0,023
30	86	1,165	0,030
35	95	1,146	0,039
40	104	1,127	0,051

\*) The density of dry air at standard atmospheric pressure at sea level at 15° C is used as a standard in the wind industry