MITIGATING THE EFFECT OF WEATHER ON ENVIRONMENTAL NOISE MEASUREMENTS

M Turner Brüel & Kjær, Denmark
M Dowie Brüel & Kjær, United Kingdom
D Manvell Brüel & Kjær, Denmark

1 INTRODUCTION

It is a skilled job making a reliable and fair environmental noise assessment. Many factors play a part:

- Can you switch on and off the noise source?
- How does the noise source vary as a function of time?
- How high is the background noise?
- Are there tones or impulses in the noise and are they prominent?

On top of this, the meteorology requirements are often difficult to fulfil, particularly if you have a deadline: the customer wants the report by next week and you are waiting for suitable weather conditions before you can measure. It is no wonder that weather requirements are sometimes glossed over. Consultants have to take a pragmatic approach.

Backed by field measurements, this paper provides a practical look at the effect of weather conditions on noise levels in order to raise awareness of the importance of meteorology in noise measurements. This paper references the requirements for measuring meteorology in BS-4142:2014[1] and compares those requirements to legislation from other countries, focusing on the propagation of sound rather than spurious noise created at the microphone. Whether short- or long-term measurements are considered, variations due to weather can add considerably to measurement uncertainty and should not be overlooked.

2 THEORY

2.1 Introduction

Noise is essentially a sound wave that, if isotropic, will radiate outwards equally in all directions from the source. Noise levels decrease as the distance increases between the source and the receiver, due to geometric dispersion. Without any form of atmospheric variation, in the ideal case, sound will decrease by 6 dB per doubling of distance. This law holds true until factors, described below, such as atmospheric attenuation begin to influence propagation.[2,3]

Outdoors we are at the mercy of the elements. A number of meteorological and atmospheric factors, which vary as a function of time, will combine to influence the propagation of sound. These factors are wind speed and direction, wind gradient, temperature and temperature gradient, humidity, and cloud cover.[2,3]

There are other factors, such as ground attenuation, that influence sound propagation; however, in the case of ground attenuation, unless we allow for effects such as snowfall or flooding due to heavy rain, the attenuation can be considered constant for the ground material in question. In the case of meteorological factors, weather is constantly changing so that, for any given measurement point, the measured result is dependent on weather conditions at the time of the measurement.[2,3]

2.1.1 Distance from source to receiver

The most important factor to consider is the distance from source to receiver. For many outdoor noise assessments, noise-sensitive receptors are relatively close to the noise source, and in this case, meteorological factors will have a negligible effect. But how close is close? There is no hard and fast rule, but the ISO 1996-2:2007 standard offers a formula and a table to calculate the resulting uncertainty, depending on the heights of the source and receiver and source-receiver distance. According to Danish guidelines, meteorological measurements are not necessary for distances of under 25 m – simply note the conditions on site.

2.1.2 Wind speed and direction

The most significant factors affecting measurements, even over short periods, are wind speed and direction. Wind blowing from the noise source towards the measurement location increases levels, and the stronger the wind, the greater the effect, until the wind becomes so turbulent that the wind itself becomes the dominant noise source. Legislation therefore places limits or makes recommendations on acceptable wind speed and direction.

2.1.3 Atmospheric attenuation

Atmospheric attenuation is a physical factor that changes the frequency content of the sound in the air. Everyone has heard a concert from a great distance: the high frequencies attenuate and only a muffled bass dominates the remaining sound. Figure 1 illustrates this effect. In the vast majority of environmental assessments, given the distances and frequencies involved, this factor is negligible.

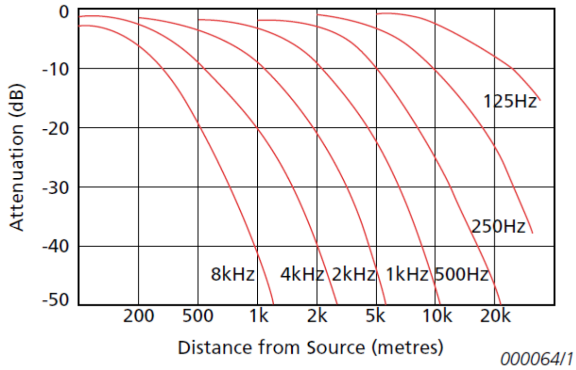

Figure 1
Attenuation of sound in air as a function of distance and frequency.[3]

2.1.4 Wind gradients

Wind gradients are caused by friction between the ground and the wind. Thus, wind speed increases with altitude, bending the path of sound to "focus" it on the downwind side, making a "shadow" on the upwind side of the source. Downwind, the level may increase by a few decibels, depending on wind speed. But when measuring upwind or side-wind, the level can drop by over 20 dB, depending on wind speed and distance (figure 2, a simplified figure). This is why downwind measurement is preferred – the deviation is smaller and the result is a conservative "worst case".

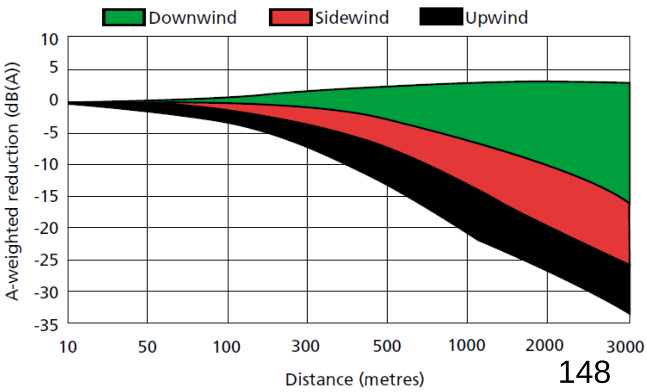

Figure 2
Noise level as a function of distance.[3]

2.1.5 Temperature gradients

Temperature gradients in the atmosphere also impact sound propagation over long distances (figure 3). On a typical sunny afternoon, air is warmest near the ground with temperature decreasing with altitude. This causes sound waves to refract upward, away from the ground and results in lower noise levels at the listener's position. In the evening, this temperature gradient will reverse, resulting in cooler temperatures near the ground. This condition, often referred to as a temperature inversion, will cause sound to bend downward toward the ground and results in louder noise levels at the listener position. Like wind gradients, temperature gradients can influence sound propagation over long distances.

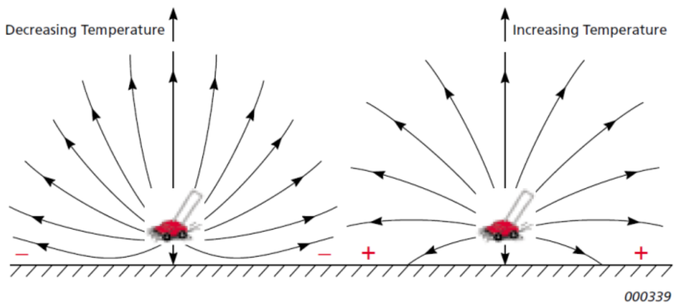

Figure 3
Effect of temperature gradients – typical day and evening scenarios.[3]

2.1.6 Absolute temperature and humidity

At 15 ºC, a decrease in relative humidity from 80% to 20% would decrease the sound level at a listener standing 800 m from the noise source by 3 dB (at 1000 Hz). Although humidity changes relatively slowly, this is a factor affecting measurement repeatability.[2]

As temperature increases, so does velocity. Fixing the relative humidity at 80%, an increase in temperature from 15 ºC to 30 ºC would decrease the sound level 800 m from the noise source by 3 dB (at 1,000 Hz). Temperature variations of this order of magnitude are not uncommon during one 24 hour period at certain times of the year in Northern Europe.[2]

3 WHAT OTHER COUNTRIES' LEGISLATION SAYS ABOUT THE WEATHER

What theory says is one matter; how legislation reflects theory is another. This section looks at how different national legislations account for weather, with particular focus on the danish legislation Måling af ekstern støj fra virksomheder MST vejl. 6/1984 (Measurement of industrial noise guidelines 6/1984 – The Danish Environmental Protection agency). Thereafter a comparison with BS-4142:2014 will be made.

3.1 Denmark

- No requirement to measure weather conditions when source-to-measurement position distance is less than 25 m.
- Wind direction may vary ±45º downwind of source.
- Measure meteorological conditions during the noise measurement itself at a representative location in open terrain between source and microphone.
- Measure wind speed and direction at 10 m when distance source to microphone exceeds 200 m.[4, 5]

- Allow to measure at heights lower than 10 m when distance from source to measurement position less than 200 m but correct wind speed using nomogram (graphical calculating device).
- Allow weather window 1: Wind speed at 10 m height: 2 m/s < u < 5 m/s and temperature gradient: –0.05 < $\Delta T/\Delta z$ < 0.05 ºC/m, where u is wind speed, T is temperature and z is height above ground
- Allow weather window 2: Wind speed at 10 m height: 0 m/s < u < 2 m/s and temperature gradient: 0 < $\Delta T/\Delta z$ < 0.05 ºC/m.
- Estimate temperature gradient allowed based on cloud cover, height of sun and time of day.
- Performance of wind meter specified in Ref 2.
  - Start threshold wind speed: 0.7 – 1.0 m/s
  - Accuracy wind speed: 0.2 – 0.5 m/s (averaged over 10 min)
  - Accuracy wind direction: 5º (averaged over 10 min)[4, 5]

3.2 ISO 1996-2:2007

- Measure wind if: (hs + hr)/r ≥ 0.1 where hs source height, hr receiver height, r distance
- Measure with conditions favorable to sound propagation, i.e., downwind with high SPL (wind blowing from source to receiver)
- Wind direction: daytime within an angle of ± 60°, night-time within an angle of ± 90°
- Wind speed, measured at a height 3 m to 11 m is between 2 m/s and 5 m/s during daytime and more than 0.5 m/s at night-time.
- Avoid strong, negative temperature gradient (e.g., bright sunshine)[6]

4 WHAT BS-4142:2014 SAYS ABOUT THE WEATHER

The guidelines on weather measurements in BS-4142:2014 are dispersed through the standard in several sections.

§6.4 Weather conditions
Section 6.4 is formulated as advice rather than rules, and is somewhat open to interpretation. This section directs the reader to monitor wind speed, and to record wind direction at the measurement location. It cautions against using the local forecast since local conditions can vary. Record the temperature at the start and finish of the measurement (this implies short-term measurements) and note cloud cover and precipitation. The only "weather window" in §6.4 is a cautionary note against measuring in wind speeds exceeding 5 m/s. Rather than stipulating a weather window, §6.4 suggests measuring more than once to take account of different weather conditions.[1]

§8.1.1 Background sound level
This section explains that background sound measurements should be performed *"under weather conditions that are representative and comparable to the weather conditions when the specific sound occurs or could occur*".[1]

§10.2 Uncertainty
This section mentions weather conditions as a point of uncertainty: "*the range of suitable weather conditions during which measurements have been taken*" recommending that uncertainty can be reduced by measuring "*under differing suitable weather conditions*".[1]

§12 Information to be reported
This section explains that all meteorological parameters should be recorded in the report.[1]

Annex A: Report examples

It is interesting to note that the role of weather measurements is not prominent in the examples given. In the case where the measurement distance is 200 m, the report states the measurements were performed in “still” wind conditions. A phrase that does appear is: “*The background sound level might be slightly lower on some occasions but is likely to be higher for much of the time depending upon weather conditions*”. [1]

Appendix B.2.2.7
This section mentions that the user should determine the likely effect of changes in the weather on the noise emissions. Ground effects such as snow are mentioned.[1]

Appendix B.2.3.1 Good practise guidelines: transmission path - General
This section is important and defines, where appropriate, a downwind angle of ±45º that is preferable to ensure favourable conditions for sound propagation. It also mentions that temperature inversions should be avoided.[1]

4.1 Discussion of BS-4142:2014

BS-4142:2014, whilst covering all important meteorological factors, seems open to interpretation stopping short of categorically defining a meteorological window for environmental noise measurements. This may be intentional and perfectly legitimate as long as consultants and public authorities understand the influence of weather and take it seriously. However, none of the report examples given in BS-4142:2014 mention logging wind speed and direction, the inference being that noting weather conditions is sufficient.

As weather conditions vary from location to location, particularly the vast majority of areas where topography is inhomogeneous (i.e., there are buildings, undulating terrain and/or significant vegetation), forecasts from meteorological websites may, at best, be indicative and, at worst, directly misleading (as pointed out in §6.4). In addition, wind data is time-variant and thus monitoring it is the only secure way of getting the data to understand and document average conditions.

The Danish and ISO 1996-2:2007 standards both specify a distance threshold over which wind measurements are necessary; this is absent from BS-4142:2014. Whilst the Danish standards specify an angle and range of wind speeds that are acceptable for a noise measurement, BS-4142:2014 makes only a caution in respect of wind speeds in excess of 5 m/s. The drawback of a weather window is that it may be contrary to the prevailing wind conditions at a given measurement location and, as such, not representative. The advantage is that the measurement is repeatable. Where the Danish standard and ISO 1996 define the height of the weather measurements (at a representative position between source and receiver), no indication is given in BS-4142:2014. Where the Danish standards specify the accuracy of the wind measurement equipment, no guidance is given in BS-4142:2014 as to what type of equipment is necessary.

5 FIELD MEASUREMENTS ACCORDING TO DANISH LEGISLATION

5.1 Methodology

To test the influence of weather, a location was needed where free field conditions could be

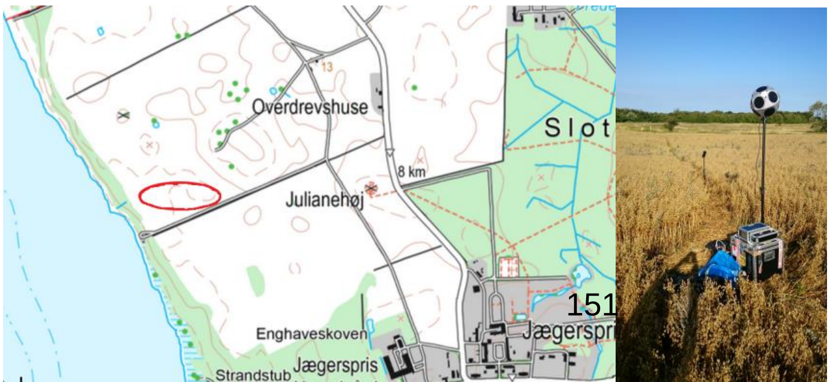

Figure 4
Location at Jægersprislejren.

assumed and where it was possible to make a lot of noise without disturbing the environment. Further to this, an omnidirectional noise source, a Brüel & Kjær Type 4292 L, was fed with pink noise. Ideally, an airport runway would have been used; however, this proved not possible and a military firing range was borrowed for one day at Jægersprislejren in the north of Zealand. The site proved satisfactory in all respects except for slight variations in terrain level. The topography was gently undulating and ground cover was relatively homogeneous with acoustically soft foliage covering the entire area.

Measurements were performed Friday 14th August, 2015 using Brüel & Kjær Type 2250 sound level meters (SLMs) and two parameter weather stations based on the WINDCAP WMT52 sensor. SLMs were setup in a straight line at 25 m and 100 m upwind and downwind of the source and a further SLM positioned at 5 m from source to confirm that noise levels were constant. The line of the SLMs was set by a subjective evaluation of wind direction at the time of setup.

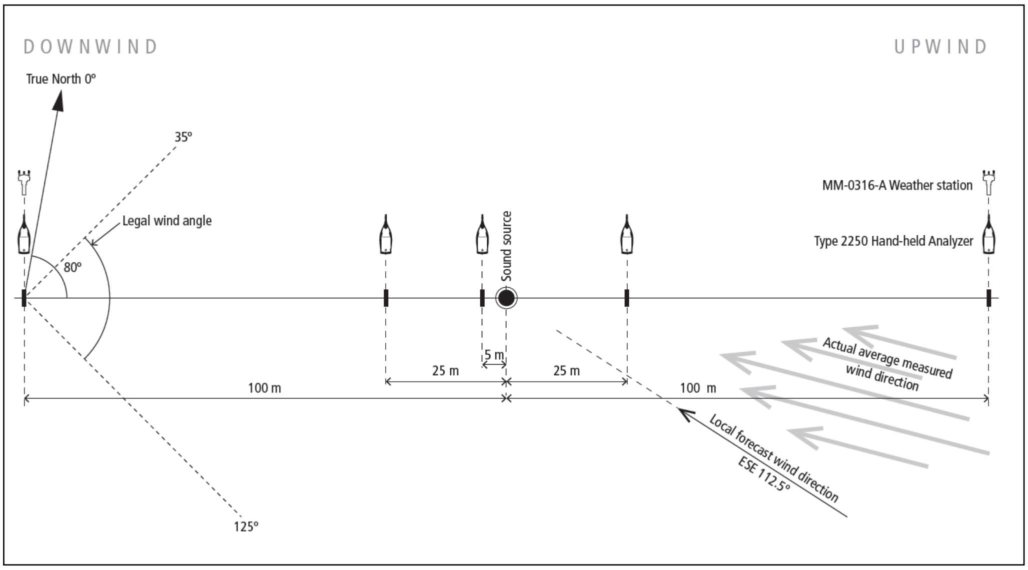

Figure 5. Equipment setup.

The wind meters were aligned with true north as indicated on the underside of the Vaisala sensor using an iPhone compass (at 100 m upwind and 100 m downwind, height 1.5 m). This was ascertained to be approximately 80º from the line of the microphones. To fulfil the Danish standards this means that all data points outside the range of 35º – 125º were invalid (i.e., ±45º). Data was saved in 3 projects over a period of 4½ hours. Wind data was corrected to a height of 10 m in accordance with the Danish requirements using a nomogram as shown in figure 6 where the y-axis represents the height over terrain and the x-axis wind speed. The upper nomogram a) is for mixed terrain with buildings, hedges and some trees whilst the lower nomogram is tall grass or a corn field.

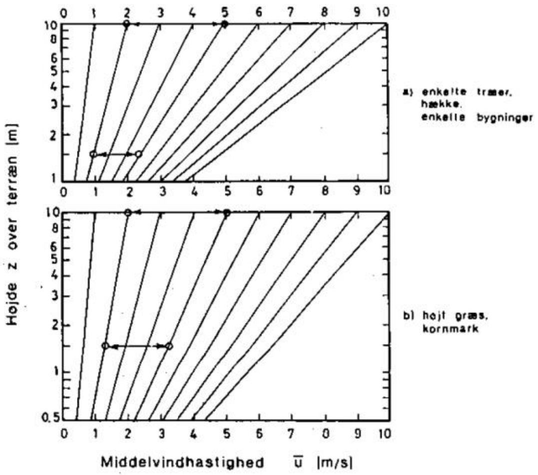

Figure 6. Nomogram from Danish standard.[4]

5.1.1 Weather forecast

The forecasts that were studied varied in comparison with each other and also according to time, but predicted winds of ESE (101.25º – 123.75º) with speeds in the range of 5 – 10 km/h. Skies were clear and hence non-compliant with the Danish standard since this will bend sound waves upward reducing noise levels.

5.2 Results

The results of the field measurements are prepared using the Danish guidelines. This is the Danish guidelines clearly specify what is legal and illegal in terms of wind speed and direction.

5.2.1 Without correction for wind

The simplest analysis of the data is just a comparison of the L_{Aeq} values in each position (with the L_{AFmax} values for reference) as shown in Table 1. For comparison, the theoretical results are calculated for ideal isotropic dispersion based on the level at 5 m with soft ground.

Table 1 Results without correction for wind speed and direction.

Pos.	Residual [L_{Aeq}]	Project 1		Project 2		Project 3		Ave Specific [L_{Aeq}]	Ideal Isotropic dispersion[7]
		Specific [L_{Aeq}]	Specific [L_{AFmax}]	Specific [L_{Aeq}]	Specific [L_{AFmax}]	Specific [L_{Aeq}]	Specific [L_{AFmax}]		
100 m up	47.0	50.0	64.4	49.8	62.4	50.2	64.1	50.0	62
25 m up	48.5	73.5	82.5	72.6	81.4	72.5	82.1	72.9	74
5 m down	49.3	87.6	89.2	87.8	89.7	87.4	89.7	87.6	88
25 m down	45.3	72.0	77.5	71.6	76.8	71.5	79.4	71.7	74
100 m down	49.4	62.4	80.8	61.7	76.2	61.8	77.4	62.0	62

The results indicate that were one to take no account of wind direction, measuring at a distance of 100 m, a level difference of approx. 12 dB(A) will occur. Put another way, in our setup, if wind direction were to reverse, the noise levels would change by approx. 12 dB(A). The downwind measurement position is legal, the upwind is not (according ISO 1996-2:2007 and Danish legislation). This difference of 12 dB corresponds with figure 2.

At 25 m the Danish standards do not require measurement of weather parameters. Nevertheless slightly higher downwind levels were expected. The reverse turned out to be the case. This is explained by the slight dip in the terrain that must have shielded the microphone more than one would subjectively expect. Note that residual levels are also lower at this point. A control measurement was performed with a different sound level meter that confirmed the correction function.

5.2.2 With correction for wind

Table 2 presents the average weather data collected on site at 100 m upwind and downwind (max values in brackets). Notice that whilst results for average wind direction are close for the two weather stations, wind speed is much higher at the downwind position. This is thought to be due to small variations in terrain level and illustrates how significant “local” wind effects can be, implying that wind data collected at one measurement location cannot be transferred to another.

Table 2. Weather data collected

Position	1		2		3	
Averages	Dir. [º]	Speed [m/s]	Dir. [º]	Speed [m/s]	Dir. [º]	Speed [m/s]
100 m upwind	91	3.1 (8.5)	95	3.1 (8.2)	90	3.5 (8.4)
100 m downwind	96	4.5 (9.1)	98	4.7 (10.3)	94	4.5 (9.0)

The Danish guidelines allow for a range of wind speeds from 2 m/s to 5 m/s. Now, since wind was measured at 1.5 m, according to the Danish standard the level should be corrected to 10 m. This significantly increases the wind speeds measured and reduces the number of data points available. Applying the Measurement Partner weather wizard to the upwind measurement position will result in zero data points since the wind at no time blew towards the “upwind” position. Table 3 therefore only presents the results of applying the weather wizard to the downwind measurement position.

Table 3 Noise levels corrected for wind speed and direction.

		1		2		3	
Position	Residual [LAeq]	Specific [LAeq]	Specific [LAFmax]	Specific [LAeq]	Specific [LAFmax]	Specific [LAeq]	Specific [LAFmax]
100 m up	n/a	n/a	n/a	n/a	n/a	n/a	n/a
100 m down	45.9	62.1	73.4	61.5	73.2	61.9	73.5

When we compare the results for the downwind position in table 1 with the results presented in table 3, the error for not removing data outside the weather window is insignificant (with the exception of the residual noise). This is due to the fact that the wind direction for the vast majority of data points was within the legal angle at the downwind measurement position and as such removing non-compliant data points did not radically alter noise levels.

5.2.3 Additional results

Figure 7 shows the correlation between wind speed and noise levels for the downwind and upwind positions for data points within the legal wind direction range. Each data point corresponds to 1 s logging. The results illustrate that the upwind results are more significantly influenced by wind speed than the downwind results, probably because the level of the source is lower upwind in relation to background noise.

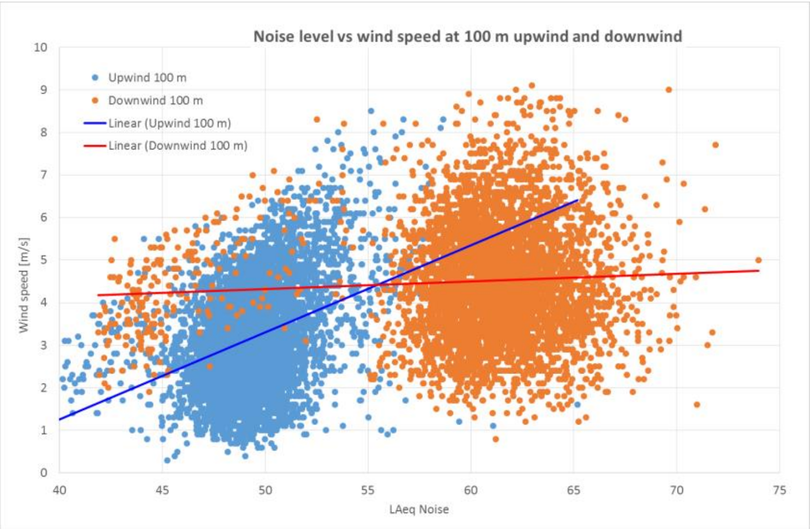

Figure 7
Noise as a function wind speed at 100 m downwind.

We can additionally conclude that wind direction is far more significant than wind speed in an environment that has little foliage. By using the Measurement Partner post processing platform grouping wind speeds with the range 35º to 125º and recalculating the LAeq for each group we can demonstrate this more clearly in Table 4).

Table 4 Upwind and downwind LAeq against wind speed (project 1).

Wind speed	Total	0 – 2 m/s	2 – 4 m/s	4 – 6 m/s	6 – 8 m/s	8 – 10 m/s
LAeq 100 m downwind	62.4	62.9	62.3	62.2	62.6	63.5
LAeq 100 m upwind	50.0	49.3	49.6	51.0	53.5	56.7

6 CONCLUDING REMARKS

This study began by looking at the theory and compared BS-4142:2014 with ISO 1996:2007 and the Danish legislation. To study the practical application of these standards, field measurements were performed in free field conditions with a steady-state sound source, using multiple simultaneous measurement positions to investigate the effect of the wind on measurement results.

The results of the field measurements demonstrate that the influence of weather cannot be taken lightly and in particular illustrates the effect of wind speed and direction on results; in the worst case, measuring upwind can significantly influence noise levels when comparing with the recommended downwind measurement position.

The study also showed how sensitive measurement results are to even small variations in terrain and how much wind measurements vary at low height between measurement positions. It is therefore recommended when performing an environmental noise measurement that wind speed and direction, as the most significant meteorological factors, are logged simultaneously with noise. In this way, the wind conditions are properly documented together with the noise results. In this way, measurement conditions can be repeated if this is necessary at a later date.

Not accurately measuring the wind speed and direction could lead to significant uncertainty in the BS-4142:2014 assessment, so much so that it could invalidate any conclusion. It is therefore recommended that BS-4142:2014 go further in clarifying how wind data is used.

7 REFERENCES

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7. http://www.masenv.co.uk/noisecalculator