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Study of secondary wind shield performance in the field

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Summary

Assessing wind farm noise commonly requires measuring noise levels in windy environments. Several sets of ambient noise level measurements have recently been carried out using pairs of sound level meters installed at two rural locations, each pair with a different wind shield arrangement. Results have been reviewed in conjunction with local meteorological data to better understand the influence that the two different wind shield arrangements have on measured sound levels. Factors considered include the potential reduction in measured sound levels due to the insertion loss of the shields and the mitigation of wind induced noise across the microphone diaphragm. The results are discussed in the context of topical publications about wind shield requirements, including comments from the UK Institute of Acoustics' document *A Good Practice Guide to the Application of ETSU-R-97 for the Assessment and Rating of Wind Turbine Noise* in May 2013.

The following definitions are used within this paper:

- Primary wind shields: this refers to the standard proprietary wind shields provided by the manufacturer of the sound level meters utilised for the study
- Secondary wind shield: this refers to the complete wind shield system which comprises the primary wind shield, the outer layer of foam around the primary shield and the void created between the primary wind shield and outer layer.

1. Introduction

Turbulent air movement across the microphone diaphragm of a sound level meter can result in extraneous acoustic signals when attempting to measure environmental noise levels in windy conditions. At increased air flow speeds and turbulence, the resulting wind-induced microphone noise may significantly influence, or ultimately corrupt, a noise measurement.

General measurement guidance documents often refer to a wind speed of 5 m/s as an upper wind speed for conducting outdoor measurements with standard wind shields (1) (2). In recognition of the higher range of wind speeds relevant to wind farm noise assessment, a number of publications recommend enlarged or enhanced primary wind shields or use of secondary wind shields to reduce the potential influence of wind-induced noise (2)(3)(4).

A widely cited publication is the ETSU document *Noise Measurements in Windy Conditions* (5) (the 1996 ETSU report) which provides details of prototype wind shields which were shown to provide significant reductions in wind-induced noise. Further, secondary wind shields which comprise a dual layer system were shown to provide the best performance in field measurements at an exposed windy site. More recently, the UK Institute of Acoustics' (IOA) *Supplementary Guidance Note 1: Data Collection* (2) (the IOA guidance) to the document *A Good Practice Guide to the Application of ETSU-R-97 for the Assessment and Rating of Wind Turbine Noise* (the IOA GPG) (6) provides a comprehensive discussion of a range of considerations related to wind shields. The IOA guidance refers to the need for further research to inform the design and selection of enhanced wind shield systems but, on the basis of current knowledge, promotes a recommended approach summarised as follows:

- Standard wind shields with a diameter typically less than 100 mm should not be used unless the measurement location is sheltered and there is evidence that wind speeds at the microphone do not exceed 5 m/s during the survey; and
- Enhanced wind shield arrangements that provide a significant reduction in wind-induced noise should be used for wind farm related measurements. Until more detailed guidance becomes available, the recommendations of the 1996 ETSU report on wind shield designs should be followed where possible.

In addition, the IOA guidance also notes the following:

- Evidence should be available to demonstrate that the wind shield insertion loss does not exceed +/-1 dB for the octave band frequencies 63 to 4000 Hz inclusive;
- Measurements of wind-induced noise based on laboratory based procedures (e.g. wind tunnels or rotating booms) may provide a means of ranking the relative effectiveness of different wind shield configurations. However, such data cannot be considered representative of the wind-induced noise that will occur in practice, due to the variable effects of turbulence in real world conditions; and
- Site specific variations in wind speed and turbulence at the microphone in any given 10 minute period mean that the relationship between 10 minute average wind speeds and the effect on L_{A90} wind-induced noise levels will not be fixed.

Accounting for the above considerations, a secondary shield arrangement offers the benefit of an enlarged shielded volume around the microphone, with less material around the microphone than an enlarged single shield design meaning it is less likely to affect the frequency response of the measurement system.

While the potential advantages of enhanced wind shield arrangements for wind farm related noise measurements are clear, information about the effect of the increased insertion loss, and the reduction in wind-induced noise, is generally limited.

2. Study Overview

The two key areas of investigation in this paper are:

- The insertion loss of the secondary wind shields; and
- The reduction in wind-induced noise provided by secondary wind shields.

The following provides a brief overview of the method of investigation.

The initial stage of the investigation involved a set of secondary wind shield insertion loss measurements in controlled conditions.

The next stage of investigation involved field studies of a secondary wind shield system at two rural sites. The sites were primarily chosen on the basis that there was an opportunity to measure with a secondary wind shield (rather than for pre-determined geographical, meteorological or acoustic reasons). Simultaneous wind speed measurements in the vicinity of the sound level meters at the height of the microphones were also available at both sites.

The results of the field measurements were then analysed to:

- Quantify the difference between measured noise levels fitted with a secondary wind shield, with and without the application of an adjustment for the relative insertion loss. The objective of this analysis was to determine if the difference was sufficient or not to warrant the adjustment of measured noise levels when using a system fitted with a secondary wind shield system for practical noise assessment purposes; and
- Compare the difference in measured noise levels obtained from systems fitted with a primary and secondary wind shields in order to establish if the secondary wind shield provided a measurable reduction wind-induced noise.

In general, the investigation was primarily concerned with the $L_{A90,10min}$ measurement parameter that is commonly used for wind farm noise assessments. However, additional consideration is also given to measured equivalent and C-weighted noise levels.

3. Insertion Loss

This section presents findings related to the insertion loss of the secondary wind shield system. The specific subjects presented in this section are:

- Details of the measurement instrumentation and test wind shield arrangements (both standard proprietary and secondary wind shield arrangements);
- A description of the method and results of the insertion loss measurements; and
- Analysis of the implications of the measured insertion loss data by comparing measured noise levels with and without adjustment for insertion loss.

3.1 Wind shields

Two different Class 1 measurement systems have been considered: a 01dB DUO and a 01dB Cube. Details of the primary and secondary wind shield arrangements for each system are detailed below. The secondary wind shields for the study were designed by Hoare Lea Acoustics, accounting for the advice detailed in the 1996 ETSU report.

Proprietary 01dB DUO primary shield.

Encloses the microphone capsule with an effective diameter of 60 mm

DUO primary wind shield (P1)

Proprietary 01dB DUO primary shield (the grey shield)

Encloses the entire DUO unit and forms an effective shield diameter of 60mm around the microphone capsule.

DUO integral primary wind shield (P2)

Proprietary 01dB Cube primary shield, on a DMK weatherproof outdoor microphone unit.

Shield encloses the microphone capsule with an effective diameter of 60 mm This wind shield type is the same as DUO proprietary wind shield (P1)

Cube primary wind shield (P3)

The secondary used with the DUO shield comprises the factory supplied primary wind shield (P1) in conjunction with an custom outer foam layer.

The outer foam layer of the secondary wind shield system has an external diameter of 175 mm and comprises 25 mm thick foam with porosity of nominally 45 pores per inch (approximately 18 pores per 10 mm).

The inner face of the outer layer is separated from P1 by a minimum of approximately 30 mm.

DUO with secondary wind shield system (S1)

The secondary shield used with the Cube comprises the factory supplied standard proprietary wind shield (P1) in conjunction with an custom outer foam layer, similar to the DUO secondary wind shield system (S1).

The base section of the secondary shield is modified to match the diameter of the DMK microphone holder rather than the diameter of the DUO case.

Cube with secondary wind shield system (S2)

3.2 Insertion loss measurements

3.2.1 Methodology

Measurements of insertion loss have been carried out in general accordance with the method detailed in Annex E of IEC 61400-11:2012 (7) for both of the DUO and Cube measurements systems. The IEC 61400-11 method requires that the insertion loss be measured using a loudspeaker generating a pink noise signal. Measurements of the sound level were repeated with and without the secondary wind shield installed on the sound level meter for a range of separation distances between the speaker and the meter. The measurements also included a control microphone, which was placed alongside the test microphone, and was fitted with a primary wind shield throughout the test.

The tests were carried out indoors, in a medium sized car park (~6000 m^3). The sound level meters were mounted on tri-pods with the microphone approximately 1.5 m above ground level (AGL), consistent with the microphone installation arrangement commonly used for far-field wind farm noise monitoring. This is a deviation from the IEC 61400-11 test method which refers to the microphone being mounted on a ground board. Additional noteworthy aspects for each insertion loss test are detailed in Table 1.

Table 1: Details of insertion loss testing

	DUO measurement system	Cube measurement system
Test system	DUO with secondary wind shield system (S1)	Cube with secondary wind shield system (S2)
Control system	DUO integral primary wind shield (P2)	Cube primary wind shield (P3)
Sound levels	One-third octave band L_{eq}	One-third octave band L_{eq}
Comments	The measurements provide a *relative* insertion loss between the DUO with secondary wind shield system and the Standard DUO integral proprietary wind shield	The measurements provide a *relative* insertion loss between the Cube with secondary wind shield system and the Standard Cube proprietary wind shield
		

The instruments used for this study apply an adjustment for wind shield insertion loss and, as a result, it is the relative insertion loss of the secondary system that is the key concern in this study. Specifically, the 01dB DUO and Cube instruments used for this study apply insertion loss adjustments for the manufacturer's primary wind shield systems, and these insertion loss values are applied within the instrument on a frequency band basis. The instruments do not provide the facility to enter alternative insertion loss values on a frequency band basis. Further, the insertion loss adjustment within each meter is incorporated as part of a total spectrum adjustment which also accounts for the influence of the proprietary microphone cone and measurement reference direction (i.e. 0° or 90° microphone orientation). The instrument manufacturers specify that one of the proprietary primary shields must be used, and that the overall measurement system conforms to IEC 61672-1:2002 (8) Class 1 requirements. Accordingly, it is the additional insertion loss of the secondary system, relative to the insertion loss that is already accounted for in the instrument for the manufacturer's primary systems, which has been investigated.
It is noted that the IOA GPG refers to total insertion loss values for a complete wind shield system, and does not refer to any requirement to adjust the measured noise levels for the insertion loss of the wind shield system.

3.2.2 Measured Insertion Loss

The measured relative insertion loss values for each system are presented in Figure 1 below. The relative insertion loss values are presented in octave bands from 63 Hz to 4000 Hz as defined in the IOA GPG, and the figure also presents the +/-1dB insertion loss performance band noted in the IOA GPG. In subsequent investigations of the effect of the insertion loss, the one-third octave band insertion loss values are used to correct for the influence of the secondary wind shield systems.

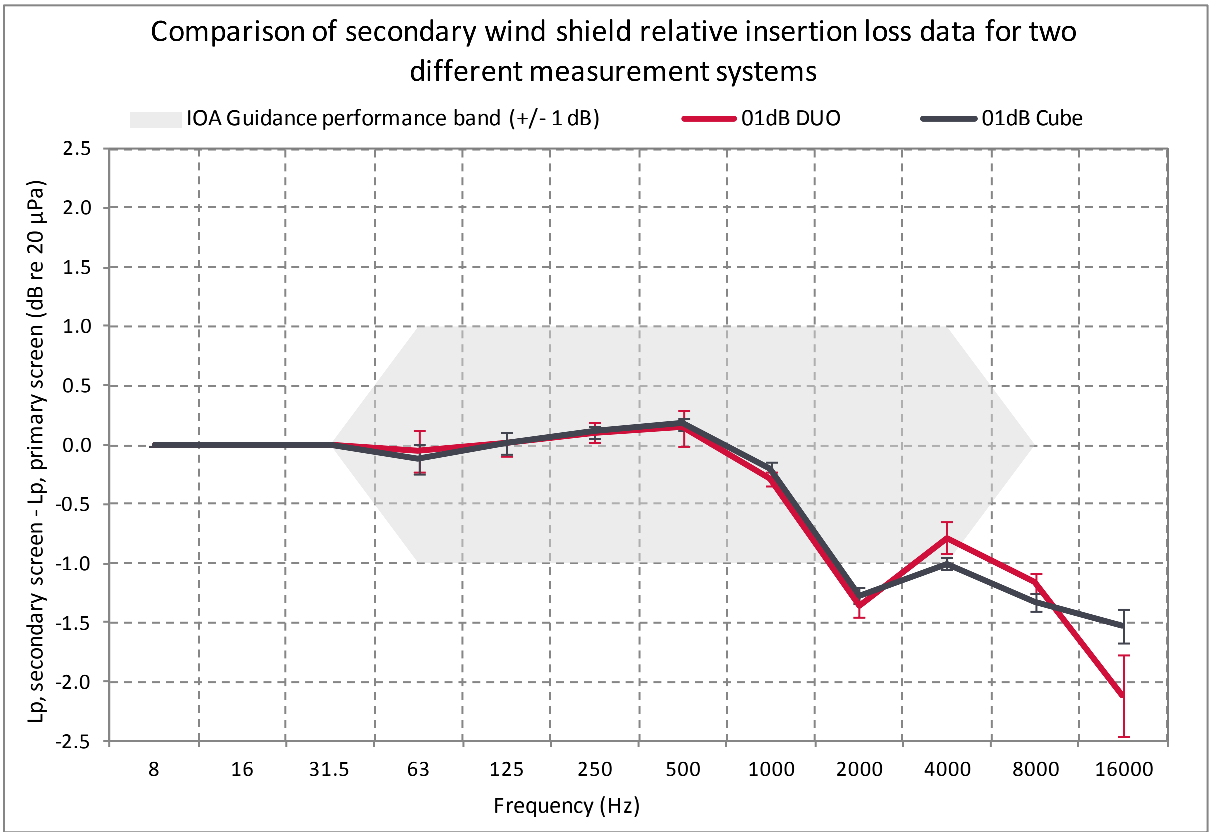

Figure 1: Insertion loss of secondary wind shield relative to primary shield

As the control systems for the two test arrangements are not the same, the measured, relative insertion loss values are not directly comparable. Nonetheless, it can be observed that the effects on each measurement system of incorporating a secondary wind shield are broadly equivalent.

The design of the secondary wind shields accounts for the recommendations of the 1996 ETSU report. In general, the measurements show that the design resulted in very minor relative insertion loss values, well below +/-0.5 dB at frequencies up to and including 1000 Hz. The results do however demonstrate a relative octave band insertion loss between -1.0 dB and -1.5 dB at the 2000 Hz octave band. In the context of the wide range of variations typically observed in environmental sound fields, this additional insertion loss at the 2000 Hz octave band is relatively minor; particularly given that the environmental sounds relevant to wind farm noise assessment are not usually dominated by sounds in this frequency range. However, further consideration is given to this effect in the subsequent section which quantifies the effect of insertion loss on actual field measurements.

3.3 Effect of insertion loss effect on measured sound levels

The implications of the measured insertion loss values presented in Section 3.2 are quantified in this section by comparing field measured noise levels with and without the application of insertion loss adjustments.

3.3.1 Insertion loss adjustment procedure

The data presented in Figure 1 in Section 3.2 demonstrates that the insertion loss performance of the secondary shields is frequency dependent. Therefore the effect that the secondary shield insertion losses can have on measured sound levels will vary depending on the frequency components of the measured sound.

Accordingly, any attempt to adjust measured noise levels using broad-band corrections may under or over compensate for the insertion loss of the wind shields. For example, while the greatest relative insertion loss in Figure 1 is approximately 2 dB at 16 kHz, subtracting 2 dB from the total measured noise levels would generally not be appropriate in most instances as the types of environmental sound fields encountered in practice are not usually dominated by such high frequencies. Although such an approach may be considered cautious for measuring pre-construction background noise levels (where insect noise at this frequency may be plausible and lower measured levels result in a more conservative assessment), the approach would underestimate measurements of operational wind turbine noise which is generally dominated by frequencies below 1000 Hz.

Concurrently, the application of frequency band adjustments to measured noise levels is problematic for the statistical noise parameters which are frequently used for both pre-construction background and compliance measurements at wind farm sites. Specifically, the total measured L_{90} noise level does not represent a sum of the octave or one-third octave band statistical noise levels. Accordingly, application of frequency band insertion loss values to measured frequency band statistical noise levels, and then summing the bands to estimate a total adjusted statistical noise level, would result in an additional and unquantified source of variation in the measurement result.

The above complications can be overcome by measuring noise levels in much shorter intervals than required for practical assessment purposes, and adopting a process that is similar to the internal adjustments applied within the sound level meter for the manufacturer's primary wind shield system. The approach, as adopted for this investigation, is summarised as follows:

- Measure total and linear one-third octave band equivalent sound levels in contiguous 1 second intervals;
- Apply the one-third octave band insertion loss values to each one second interval;
- Apply frequency weightings to each one-third octave band;
- Recalculate the total sound level for each 1 second period by summing the adjusted one-third octave band sound levels; and
- Calculate the 10 minute L_{90} level from the adjusted sets of 1 second equivalent noise levels.

This approach to the derivation of statistical noise levels using equivalent noise levels is consistent with the provisions of Section 8.4.4 of ISO 1996-2:2007 (9). The alternative procedure referred to ISO 1996-2:2007 may apply in jurisdictions where a Fast time-weighting is specified for the measurement of statistical noise levels. However the approach based on 1 second equivalent noise levels has been consistently applied throughout this study to all measurement data from all measurement systems, including insertion loss measurements, to enable meaningful comparisons to be made.

3.3.2 Measurement sites

Two sets of ambient noise level measurements have recently been carried out using pairs of sound level meters installed at two rural locations as detailed in Table 2.

Table 2: Details of field measurement sites

		Measurement systems		
Site	**Description**	**A**	**B**	**Weather**
1	A semi-rural location. The landscape was generally flat with a moderate gradient. Vegetation primarily comprises farm land, with intermittent clusters and trees and shrubs. There are approximately 6 dwellings within 500 m and a rural access road to the west.	Standard DUO integral primary wind shield (P2)	DUO with secondary wind shield system (S1)	Local wind speed, wind direction and rain data were collected from a Vaisala WXT520 weather station installed approximately 75 m from the two, side by side sound measurement systems.
2	An operating wind farm in a rural, coastal location. Approximately 8 turbines are located within 1200 m of the monitoring location and wind turbine sound is a dominate component of the noise environment. The landscape is moderately hilly, vegetation primarily comprises farm land. This site can be considered as windy compared with Site 1.	Standard DUO integral proprietary wind shield (P2)	DUO with secondary wind shield system (S1)	Local wind speed, wind direction and rain data was collected from a Vaisala WXT520 weather station installed beside the sound measurement systems at a distance of approximately 1.5 m.

At each site, Measurement System A and B were installed approximately 1 m to 2 m apart with each microphone located approximately 1.5 m AGL. Local weather conditions were also measured at 1.5 m AGL. The Vaisala WXT520 weather stations do not utilise cup anemometers, tipping buckets or other moving parts which can generate noise in the vicinity of the sound measurement system.

The data from Measurement System A (primary wind shields) at each site was not referenced as part of the investigation of insertion loss; this data was captured for the purpose of assessing wind induced noise considerations, as presented in Section 4 of this paper.

3.3.3 Results

Data from Measurement system B at each site has been analysed to estimate the influence of the insertion loss of the secondary wind shield on measured sound levels. Specifically, for each set of data $L_{A90,10min}$ sound levels have been calculated from two (2) data sets:

- 1 second L_{eq} one-third octave band sound level data (Unadjusted)
- 1 second L_{eq} one-third octave band sound level data corrected for insertion loss using the measured relative insertion loss data detailed in the above section (Adjusted).

Comparing these two (2) sets of $L_{A90,10min}$ data provides an estimate of the influence of insertion loss on measured levels. Results are presented in Figure 2 and Figure 3 below which show the difference in sound level between the unadjusted and adjusted data sets.

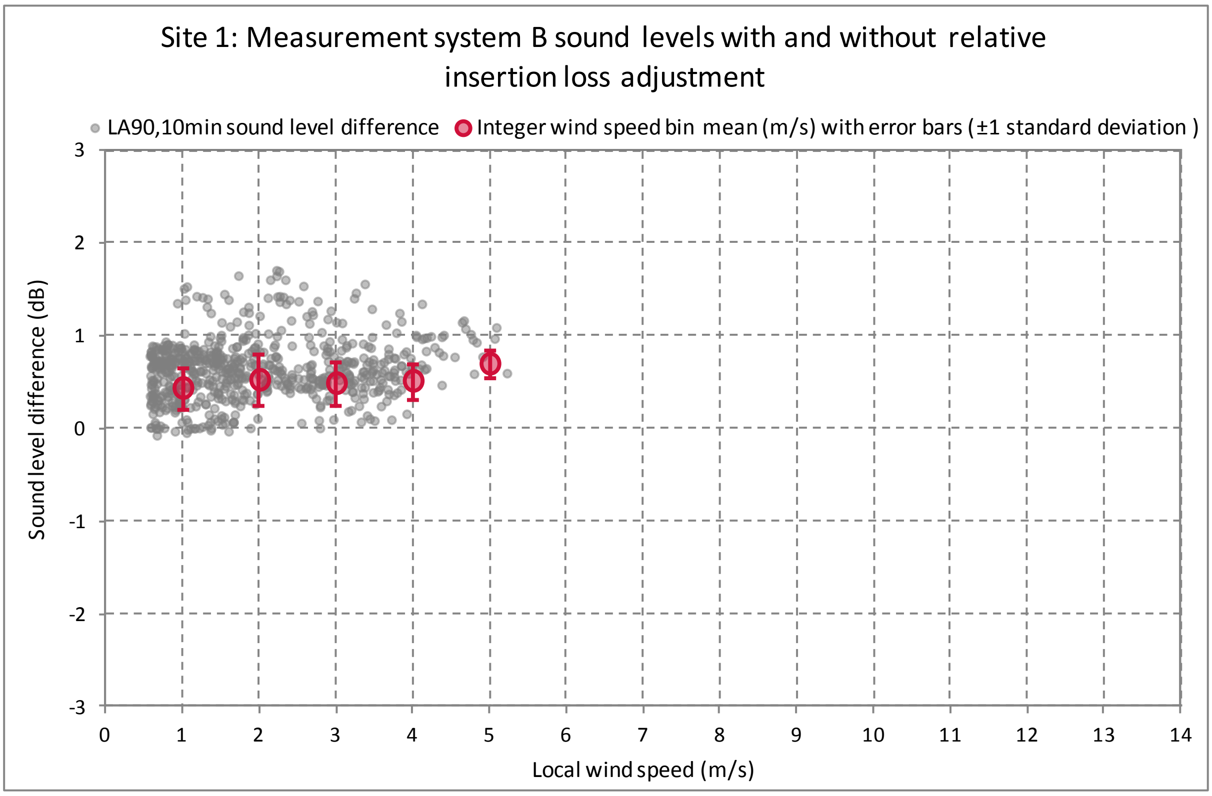

Figure 2: Site 1 - sound level difference for Measurement System B with a secondary wind shield installed, with and without adjustment for insertion loss

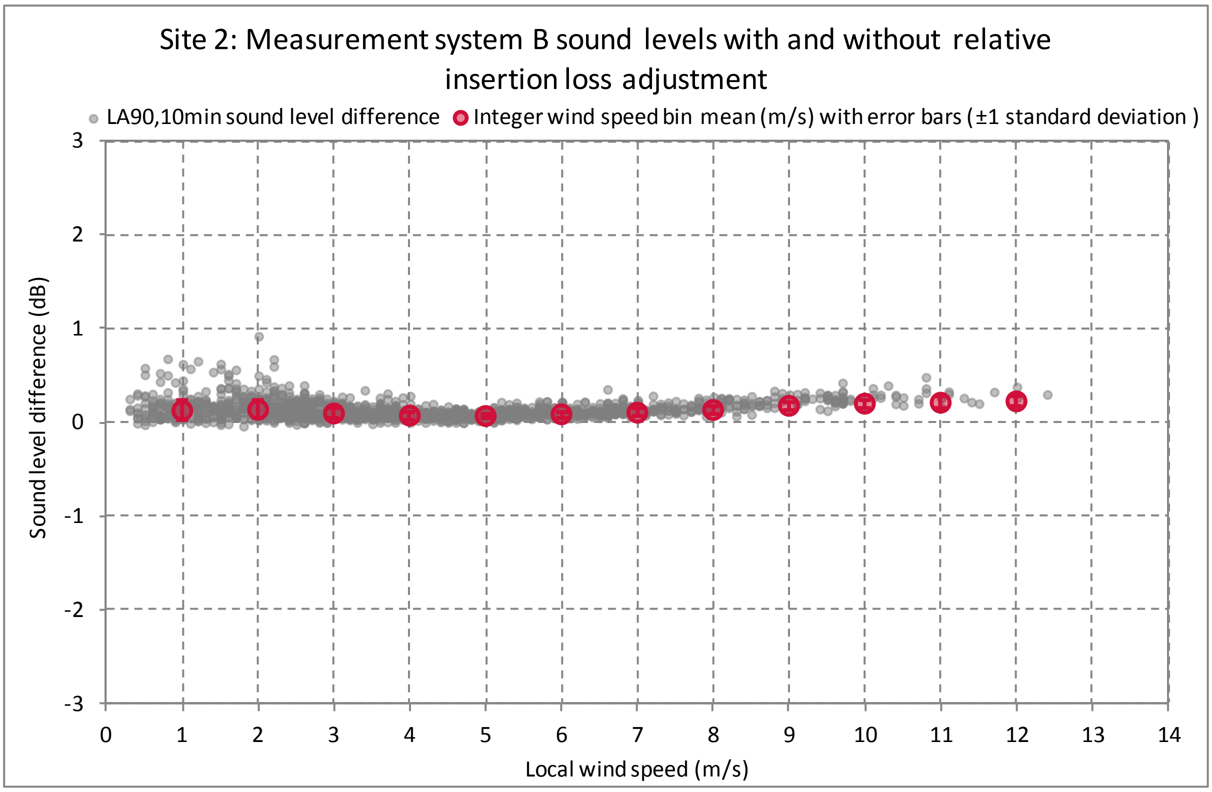

Figure 3: Site 2 - sound level difference for Measurement System B with a secondary wind shield installed, with and without adjustment for insertion loss

For Site 1, the effect of insertion loss results in noise levels approximately 0.5 dB lower on average. Noise conditions at the site were generally consistent with a rural area characterised by occasional distant intermittent traffic and wind disturbed vegetation. However, a high voltage overhead power line passes near to the area and was observed to generate electrical noise at a range of frequencies above 1000 Hz. These higher frequencies coincide with the frequency range of the secondary wind shield system that exhibits greater insertion loss values (i.e. 2000 Hz octave band). This effect is likely to have been a key contributing factor to the observed difference between unadjusted and adjusted noise levels.

For Site 2, the effects of insertion loss are less pronounced with an average sound level difference of around 0 dB. This may be a result of the sound environment at the Site 2 monitoring location being dominated by turbine sound. Specifically, the monitoring location is 200 m to 400 m from multiple turbines for which mid and low frequency components of the turbine sound are likely to be more prevalent. As the measured relative insertion loss values in the mid to low frequency region are very small, so too would be the expected effects of insertion loss on measured sound levels.

An important aspect of this analysis is that insertion loss corrections have been applied directly to measured levels, implying that the sound levels recorded by the measurement systems are representative of the incident sound field. In other words, it is assumed that there are no significant effects of wind-induced noise on the microphone. At the higher wind speeds where this assumption is not valid, the calculated sound level differences are likely to be less reliable.

3.4 Discussion

The following key points are noted from the study of insertion loss:

- The relative insertion loss of the secondary wind shield system is negligible at the low and mid frequencies that are most relevant to the measurement of operational wind turbine noise.
- The relative insertion loss of the secondary wind shield system may result in a greater reduction in measured background noise levels in situations where higher frequency sounds represent a greater component of the background noise environment. These reductions in measured noise levels are however marginal and, in the context of wind farm assessments, a marginally lower pre-construction background noise measurement will generally represent a cautious approach.
- The procedure for post-processing statistical measurement parameters in order to adjust for frequency band insertion losses is onerous and impractical as a general measure for routine wind farm studies – particularly in jurisdictions where statistical parameters must be derived using a Fast time weighting.
- Subsequent sections demonstrate significant benefits of secondary wind shields for the control of wind induced noise. In contrast, the measurement variation related to insertion loss could be considered negligible in comparison, for the study sites investigated.

4. Effect of wind-induced noise

This section presents the findings of the study related to the effectiveness of the secondary wind shield system for reducing wind-induced noise at the microphone.

4.1 Variation in sound levels

The investigation of wind induced noise was based on comparison of sound levels measured by Measurement systems A and B (as detailed in Section 3) in different wind conditions.

In addition to wind-induced noise related effects, variations in sound levels measured by the two separate measurement systems at each will occur as a result of:

- Minor inherent variations between systems within the tolerances defined for Class 1 instrumentation;
- Slight differences in the sound field incident on each microphone; and
- Minor differences in insertion loss of the primary and secondary wind shields.

To provide the best opportunity of evaluating the difference solely related to wind induced noise, it is necessary to adjust the measurements, where practical, for the estimated effect of the above sources of variation.

Accordingly, while the discussion presented in Section 3 demonstrated that insertion loss adjustments for secondary wind shield systems are not considered to be warranted for practical noise assessment purposes, all subsequent analysis of Measurement System B results presented in this section have been adjusted for insertion loss in the same manner described in the preceding section.

To determine an estimated offset adjustment for the sources of variation related to Class 1 systems and incident sound field variations, the measurement data from the two measurement systems has been compared at low wind speeds to identify any systematic differences. The analysis considers data where average local wind speeds are ≤ 1.1 m/s and maximum local wind speeds during each measurement interval are ≤ 2.1 m/s. These values were chosen according to the availability of data at comparatively low wind conditions where it is considered that the potential influence of wind-induced noise on the microphones is negligible. The results are presented in Figure 4 and Figure 5 below. Each chart shows the scatter of sound level difference values as a function of wind speed.

At these low wind speeds, the figures show that there is no apparent correlation between wind speed and sound level, consistent with the expectation that wind induced noise on the microphone is not significant. The light red band on each chart shows the mean sound level difference (for all wind speeds) ± one standard deviation.

Figure 4 shows that the average offset value between Measurement System A and B at Site 1 is approximately 0 dB. In other words, there is little systematic difference between the two measurement systems at Site 1. Figure 5 shows that at Site 2 the average difference is approximately 1.2 dB. These values have been subsequently applied as estimated offsets in the analysis of measured differences at higher wind speeds.

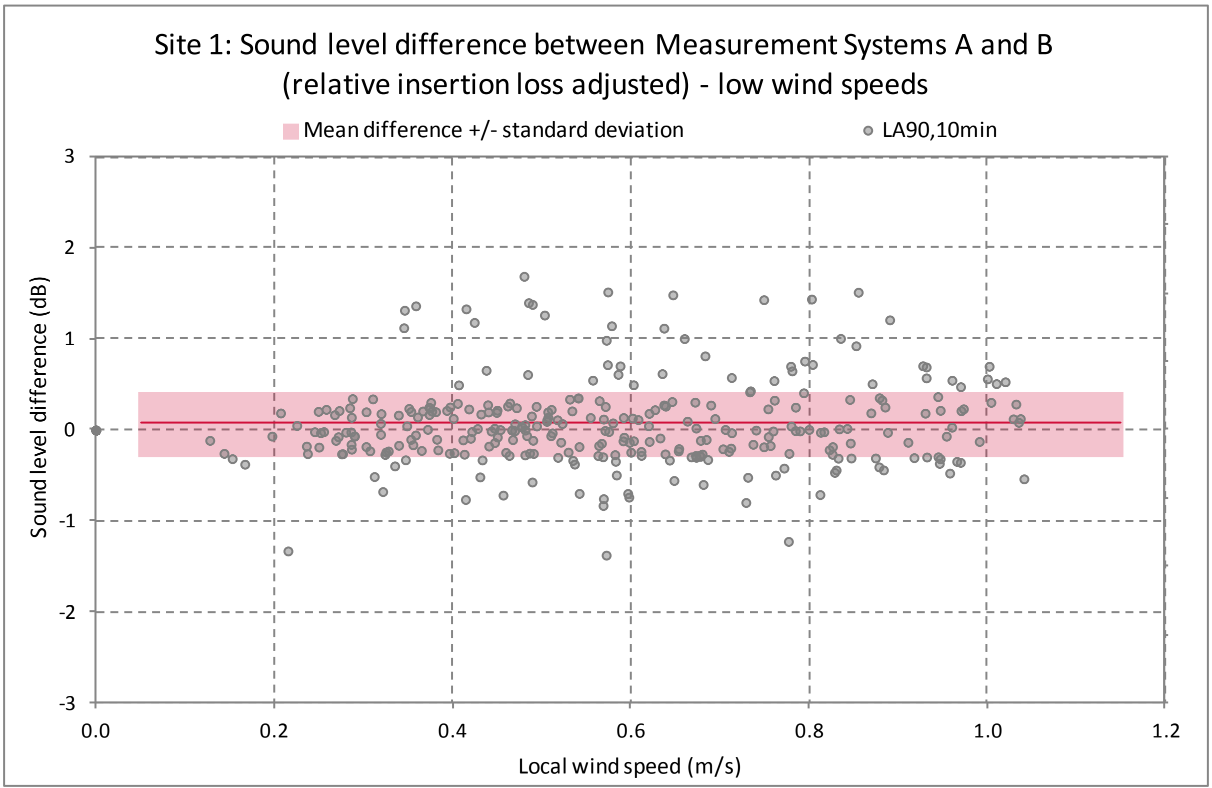

Figure 4: Site 1 - sound level difference between Measurement Systems A and B (relative insertion loss adjusted) at low wind speeds

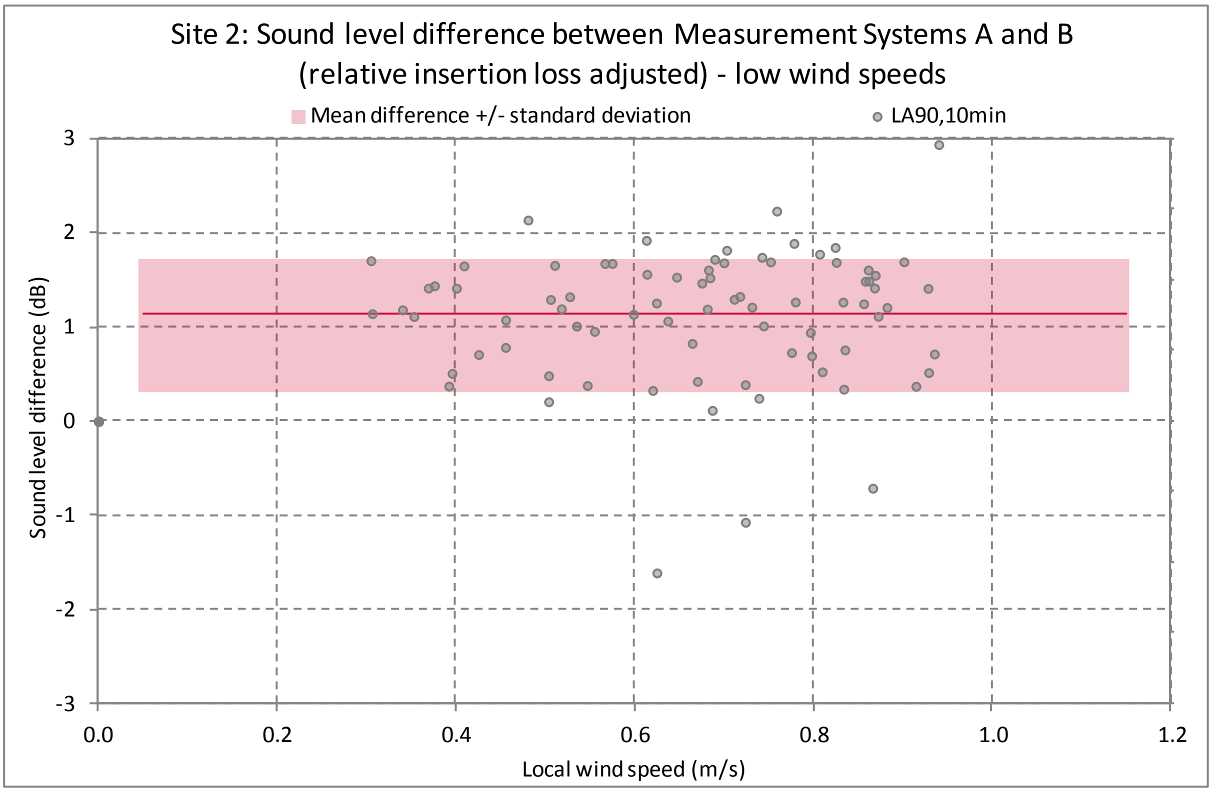

Figure 5: Site 2 – sound level difference between Measurement Systems A and B (relative insertion loss adjusted) at low wind

4.2 Comparison of measured sound levels at Site 1

Sound levels measured by Measurement Systems A and B at Site 1 have been compared to estimate the influence of wind induced noise. Specifically, the following data has been compared:

- $L_{A90,10\ min}$ sound levels from Measurement System A
- $L_{A90,10\ min}$ sound levels from Measurement System B adjusted for the insertion loss of the secondary wind shields (on a 1 second L_{eq} basis), with an offset[1] applied arithmetically to each 10min sound level as an estimate of the potential systematic variation between measurements systems.

The results of this comparison are shown in Figure 6 and Figure 7 below.

Figure 6 shows that the measured sound levels from each system are generally similar for the range of encountered sound levels (35-50 dB) and wind speeds (0-6 m/s).

Consistent with this trend, Figure 7 presents the difference in sound levels as a function of wind speed and indicates that at this measurement site, the average sound level difference is approximately zero.

[1] In the case of Site 1, the offset was estimated to be approximately 0 dB and therefore the adjustments were negligible.

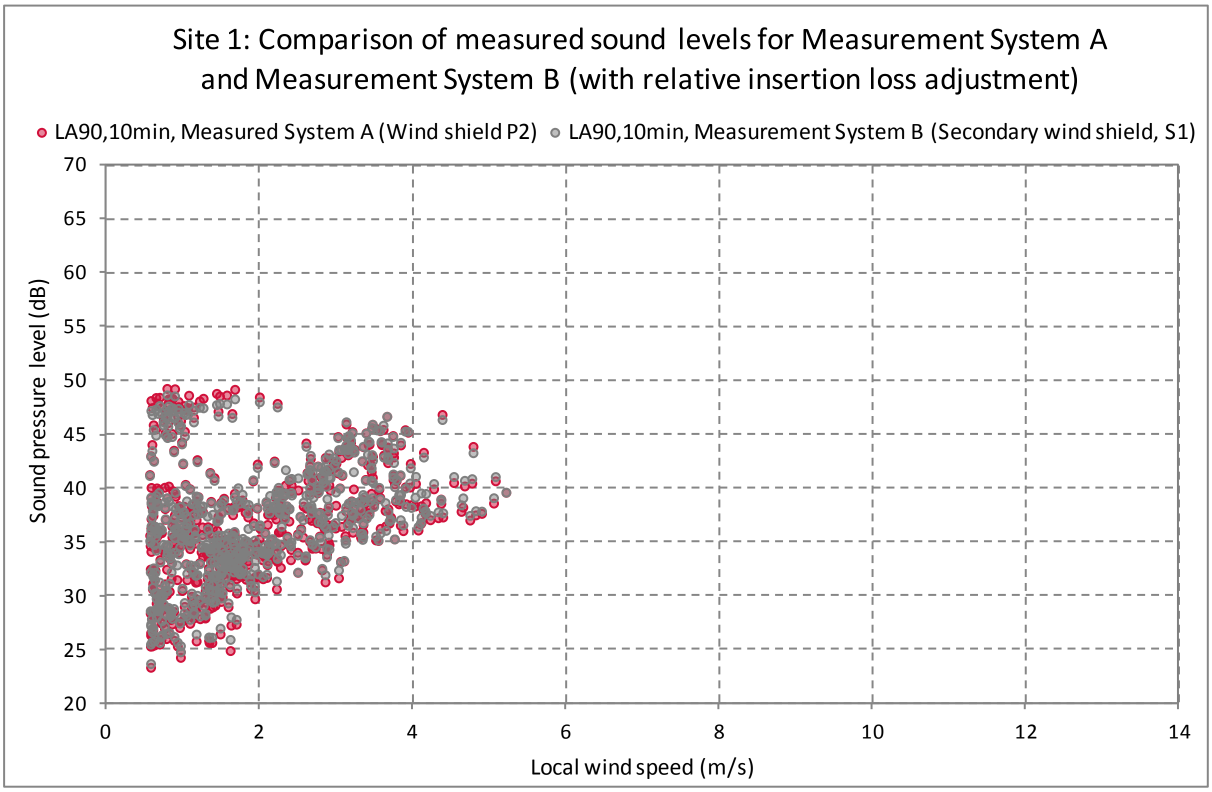

Figure 6: Site 1 – comparison of measured sound levels for Measurement Systems A and B (with relative insertion loss adjustment), all available local wind speeds

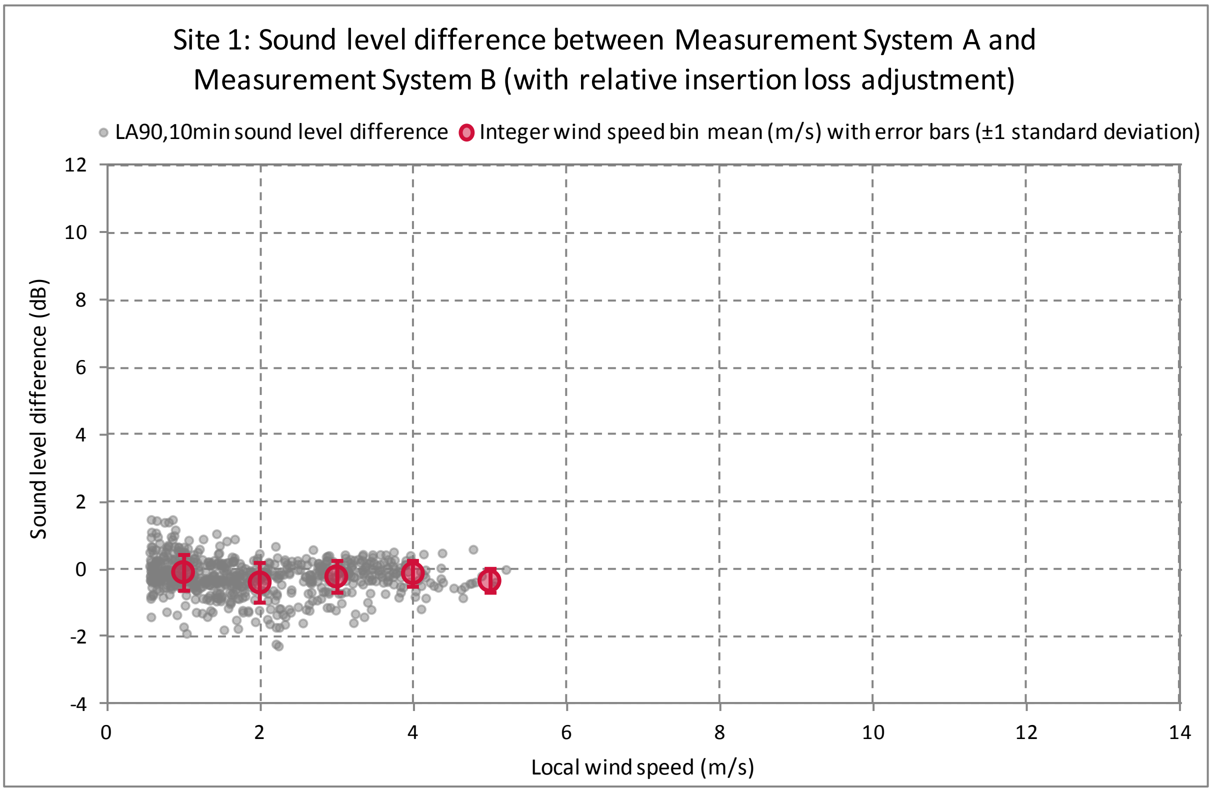

Figure 7: Site 1 - sound level difference between Measurement Systems A and B (with relative insertion loss adjustment) vs all available local wind speeds

The observed variation in differences may potentially be partly attributable to differences in the level of wind-induced noise at the microphones. However, at these relatively low wind speeds, it is considered more likely that the variation is attributable to other sources, thus indicating the limitations of applying average systematic offsets to the data to correct for differences in the levels measured by System A compared with System B.

While the comparison does not directly quantify the relative benefits of a secondary wind shield system for the control of wind-induced noise at the microphone, the results are consistent with general guidance that primary wind shields are likely to be acceptable for measurements at wind speeds (at microphone height) up to 5 m/s. Owing to the low range of available wind speeds at Site 1, no further analysis of this data was undertaken.

4.3 Comparison of measured sound levels at Site 2 – A-weighted L_{90} Levels

The same comparison of measured levels has been carried out for the data collected from Site 2. Results are presented in Figure 8 and Figure 9.

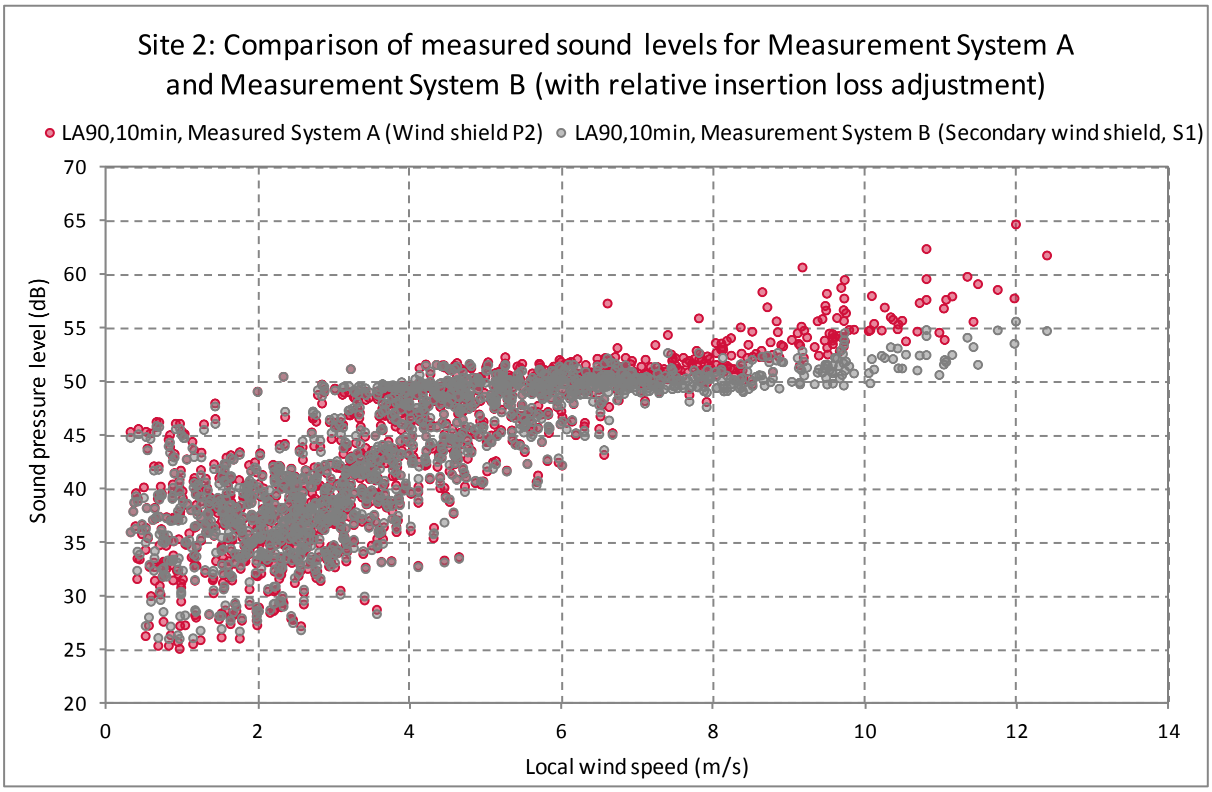

Figure 8: Site 2 - comparison of measured sound levels for Measurement Systems A and B (with relative insertion loss adjustment), all available local wind speeds

Figure 8 shows the difference in measured sound levels at Site 2 between the primary and secondary wind shields across a wide range of different noise levels (25-65 dB) and wind speeds (0-12 m/s). The influence of the nearby, pitch-controlled wind turbines is apparent in the data, with measured noise levels reaching a plateau of approximately 50 dB $L_{A90,10min}$ across the wind speed range (at the microphone) of approximately 4-8 m/s.

The figure shows that above approximately 8 m/s (local wind speed at 1.5 m height), the difference in measured noise level between the units becomes much more pronounced. The unit with the secondary wind shield measured lower noise levels. This is expected to be due to the secondary shield providing improved mitigation of extraneous wind induced noise on the microphone.

Between 9 and 10 m/s, the trend of the data from Measurement System B (which has the secondary wind shield system) also begins to progressively increase. This could indicate the onset of wind-induced noise at the microphone, but could equally indicate the increasing influence of the background noise environment (i.e. wind noise associated with disturbance of local vegetation). The source of this increase has not been investigated as part of this study.

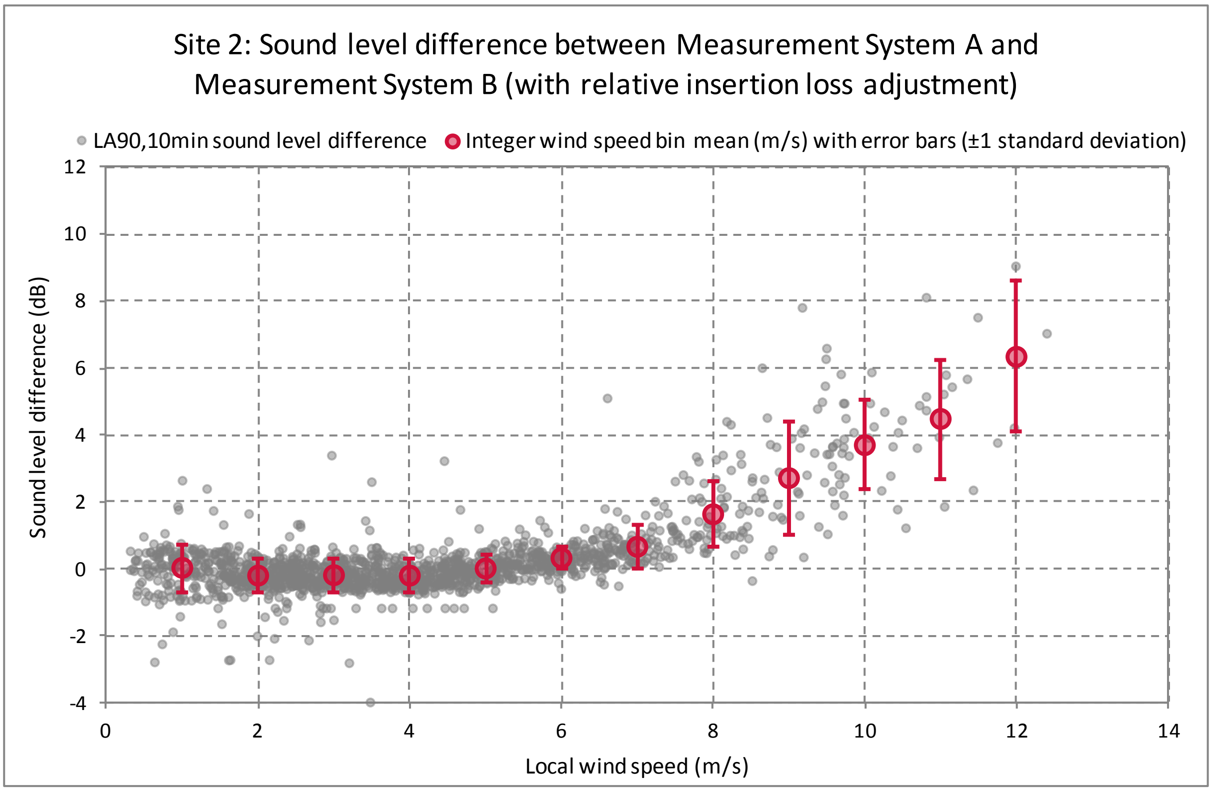

Figure 9: Site 2 - sound level difference between Measurement Systems A and B (with relative insertion loss adjustment) vs all available local wind speeds

Figure 8 and Figure 9 suggest that, below 4-5m/s, it seems there is little difference between systems with primary or secondary wind shields. As with Site 1, this finding is consistent with primary shields being adequate for measurements at wind speeds up to 5m/s at microphone heights. With increasing wind speed, the results exhibit increasing differences between the two measurement systems. Consistent with the data illustrated in Figure 8, this appears to support the notion that the secondary wind shield is providing better control of wind-induced noise at the microphone. However, these results cannot be taken as a direct measure of the effectiveness of the secondary wind shield system, as wind-induced noise for Measurement System B is unknown and the measured difference may be limited by the effects of increasing ambient noise levels with increasing wind speeds (i.e. the difference in wind-induced noise at each microphone is potentially masked by increased ambient noise levels).

4.4 Site 2 – Equivalent and C-weighted noise levels

Equivalent and C-weighted noise levels are generally considered to be unsuitable parameters to measure in windy conditions, owing to the significantly increased potential for corruption of the measurements as a result of wind-induced noise at the microphone. Notwithstanding this, the analysis presented in the preceding sections has been reproduced for A-weighted equivalent and C-weighted statistical noise levels; the results are presented in Figure 10 and 11 respectively below.

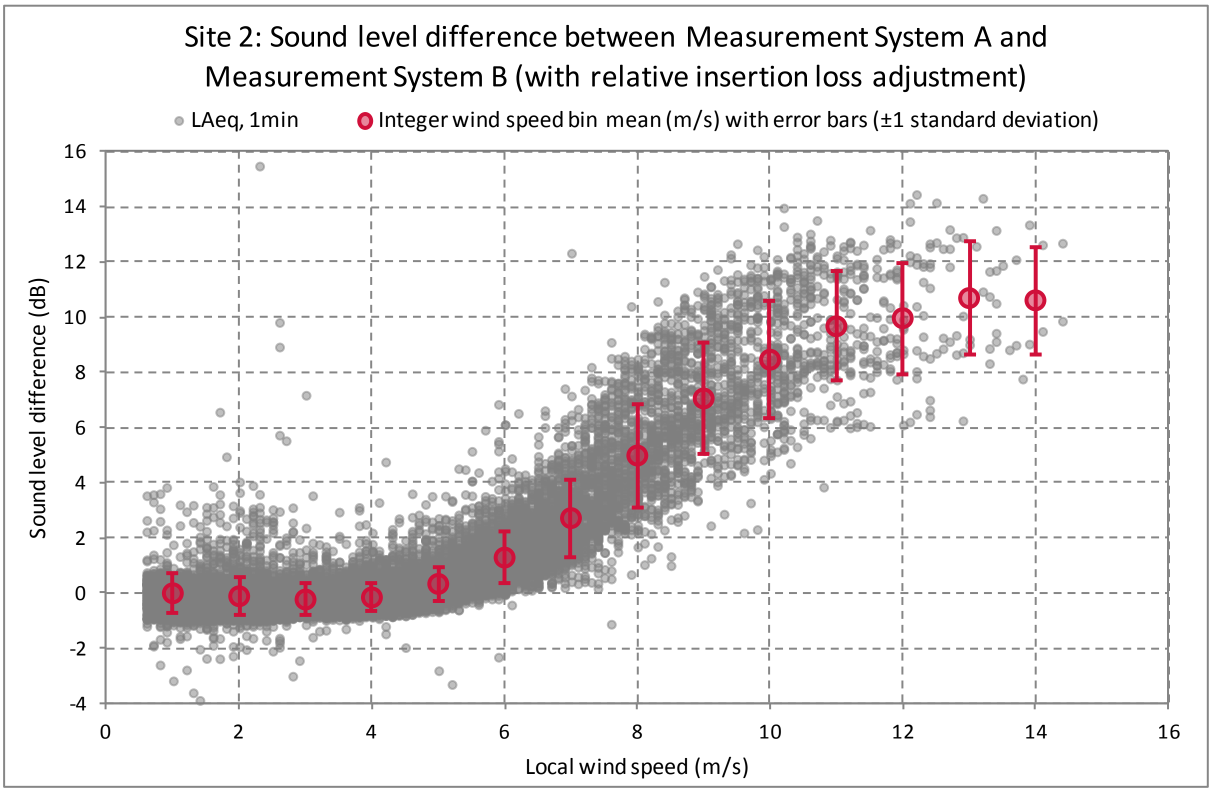

Figure 10: $L_{Aeq,1min}$ sound level difference between Measurement Systems A and B (with relative insertion loss adjustment) vs all available local wind speeds (Site 2)

The results presented in Figure 10 illustrate a much greater difference between Measurement Systems A and B for equivalent noise levels than was exhibited for statistical noise levels. Notwithstanding the greater relative benefit of the secondary shield system, L_{Aeq} based measurements carry a greater risk of wind-induced noise influences associated with brief wind gusts and therefore the secondary wind shield system cannot be assumed to be reliable for the measurement of equivalent noise levels in high wind conditions.

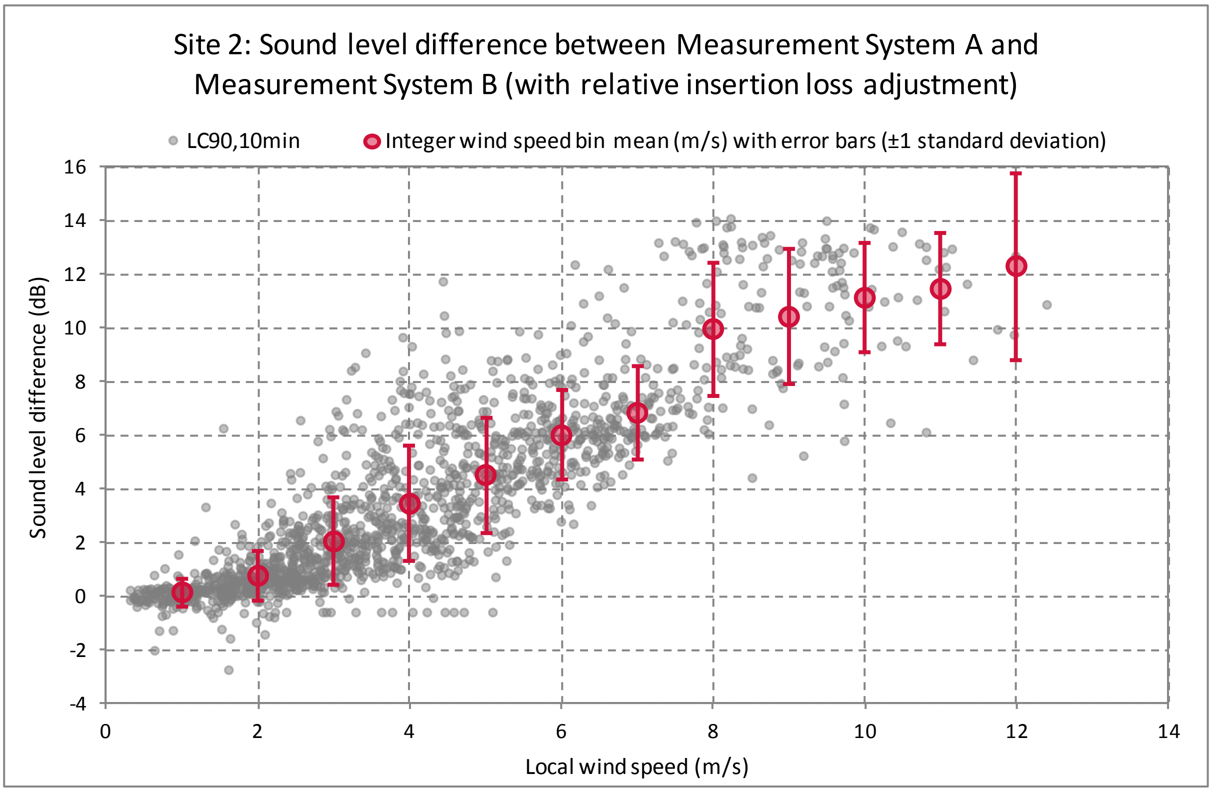

Figure 11: $L_{C90,10min}$ sound level difference between Measurement Systems A and B (with relative insertion loss adjustment) vs all available local wind speeds (Site 2)

Consistent with the equivalent noise level results, the C-weighted differences presented in Figure 11 again illustrate larger differences between Measurement System A and B relative to A-weighted statistical noise levels (cf, Figure 9). This is considered to be a result of the increased influence of air turbulence at lower frequencies, and the increased sensitivity of C-weighted noise levels to low frequency noise. The differences between the two systems are noted to be significant even at wind speeds below 5m/s local wind speed (at 1.5m above ground level).

These results demonstrate that the secondary wind shield system provides significantly better protection from lower frequency wind-induced noise at the microphone. This result is consistent with the 1996 ETSU report. However, as with equivalent noise levels measurements, C-weighted measurements carry a greater risk of wind-induced noise influences. Accordingly, the secondary wind shield system cannot be assumed to be reliable for the measurement of equivalent noise levels in high wind conditions.

5. Discussion

The following conclusions have been reached from this study.

Insertion Loss

The tested secondary wind shield introduces a measurable increase in insertion loss at frequencies around 2000 Hz and above. However, field trials have demonstrated that the influence of the change in insertion loss is minor to negligible for practical wind farm noise measurements. In particular, the reduction in measured noise levels (less than 0.5 dB when considering noise spectra associated with operational wind turbines) associated with the insertion loss of the secondary wind shield system is negligible when compared to other sources of environmental noise variation, and when compared the more significant beneficial effects with respect to the reduction of wind-induced noise at the microphone.

Based on these investigations, post-processing of measurement data for the increased insertion loss of a secondary wind shield is not considered to be warranted for practical noise assessment purposes. Particularly given the inherent complexities that have been described in relation to frequency band insertion loss adjustments for the statistical measurement parameters frequently used for wind farm noise assessments. Notwithstanding this finding, a manufacturer supported secondary wind shield system, with associated integrated adjustments within the sound measuring system, would be a worthwhile development.

Wind-Induced Noise at the Microphone

In terms of the primary objective of wind shields for the control of wind-induced noise, the study has shown the following in relation to the site considered.

- The results are consistent with general measurement guidance which indicates that standard primary wind shield arrangements are satisfactory for the measurement of A-weighted L_{90} environmental noise levels at microphone-height wind speeds up to 5m/s.
- The secondary wind shield arrangement provided a significant improvement in the control of wind-induced microphone noise.
- These benefits were primarily demonstrated in relation to the measurement of A-weighted L_{90} environmental noise levels. While the reliability of the secondary wind shield arrangement for the measurement of A-weighted equivalent or C-weighted L_{90} noise levels is uncertain, the secondary wind shield also demonstrated significant benefits for these parameters.
- The magnitude of the improvements presented in this study represent minimum values, owing to limitations of the study related to ambient noise levels at the survey locations.

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