Fourth International Meeting on Wind Turbine Noise

Rome Italy 12-14 April 2011

Comparison of predicted wind farm noise emission and measured post-construction noise levels at the Portland Wind Energy Project in Victoria, Australia

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ABSTRACT

During the planning phase for their approved Portland Wind Energy Project (PWEP), developers Pacific Hydro presented predicted wind farm noise emission curves in their design application. These curves were developed based on requirements of New Zealand Standard 6808:1998 *Acoustics - The assessment and measurement of sound from wind turbine generators* (NZS6808:1998) which was applicable at the time the PWEP Design Application was submitted. The prediction method recommended by NZ6808:1998 is based on hemispherical spreading and, as noted by the Standard, '*is generally accepted as being slightly conservative'*. Several stages of PWEP are now in operation and Pacific Hydro has carried out several post-construction monitoring campaigns, in accordance with NZS6808:1998, as required by their planning permits. This paper compares the results of the post-construction monitoring campaigns with the levels of predicted wind farm noise emission which were developed during the planning phase of PWEP. An average level difference between the predicted and measured data sets is determined to quantify the conservatism in the predicted levels. In addition the prediction methods of International Standard 9613:1996 *Acoustics – Attenuation of sound during propagation outdoors: Part 2: General calculation method* (ISO 9613-2:1996), are considered to investigate whether they offer any significant improvements in accuracy of predictions and whether particular parameters may be identified as the source of the conservatism.

INTRODUCTION

During the planning phase for their approved Portland Wind Energy Project (PWEP), developers Pacific Hydro presented predicted wind farm noise emission curves in their design application. These curves were developed using the simple prediction algorithm from New Zealand Standard 6808:1998 *Acoustics - The assessment and measurement of sound from wind turbine generators* (NZS6808:1998) [1], which was applicable at the time the PWEP Design Application was submitted.

Multiple stages of PWEP are now in operation and Pacific Hydro has carried out several post-construction monitoring campaigns, in accordance with NZS6808:1998, as required by their planning permits. The collection of this data presents an opportunity to compare post-construction monitored noise levels with the levels of predicted wind farm noise emission according the NZS6808:1998, which is generally considered to be conservative. Moreover, the post-construction data can also be compared to levels of wind farm noise emission predicted using ISO9613 [2][3], to contrast with the results from NZS6808:1998.

An analysis of the post-construction data and various arrangements for wind farm noise emission predictions are presented herein. The post-construction noise levels are analysed for the range of wind speeds recorded during the monitoring surveys. Noise emission predictions are analysed for the wind speed range 5-10m/s at 10m above ground level (AGL).

The primary objective of this paper is to quantify the degree of conservatism in the NZS6808:1998 predictions for the properties where monitoring occurred. A secondary objective is to establish whether, as expected, predictions calculated using ISO9613 are less conservative or, indeed more accurate.

SITE DESCRIPTION

The PWEP is located in south western Victoria and comprises of the four following sites:

- Yambuk (PWEP I)
- Cape Bridgewater (PWEP II)
- Cape Nelson South (PWEP III)
- Cape Nelson North and Cape Sir William Grant (PWEP IV)

This paper considers data collected during the development of two of the PWEP projects, the Cape Bridgewater Wind Farm (PWEP II) and the Cape Nelson South Wind Farm (PWEP III). These are presented in Figure 1.

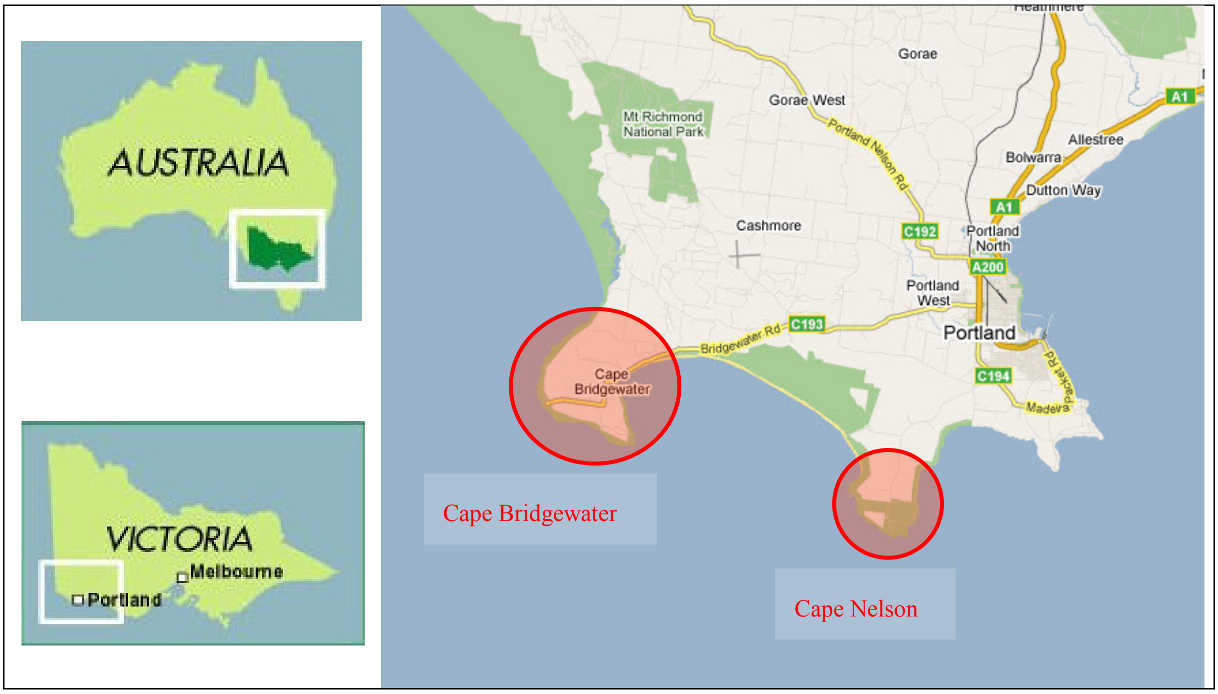

Figure 1: Study site locations

The Cape Bridgewater Wind Farm, PWEP II, essentially comprises two turbine areas (northern and southern) along Cape Bridgewater's western side. The coastal escarpment on the west of the cape is 30 to 40m above sea level, and away from it the area features a gently undulating landscape. The northern area offers a slightly more complex topography than the southern area. Most native vegetation has been cleared from this site and grazing pasture is predominant.

The Cape Nelson South Wind Farm is located in a headland surrounded by coastal cliffs and escarpments which rise between 40 to 70m above sea level. The cape itself undulates slightly, generally rising up to Picnic Hill in the centre at 110m, and from this point the landform slopes downwards undulating gradually inland to the north east at an average height of 70-80m before dropping down to around 30m closer to Portland. Although predominantly open, the pastoral setting supports scattered stands of low remnant vegetation. The western coastal edge and southern section of the Cape have a dense cover of low remnant vegetation.

PREDICTED WIND FARM NOISE EMISSION

The New Zealand Standard

The New Zealand Standard 6808:1998 *Acoustics - The assessment and measurement of sound from wind turbine generators* (NZS6808:1998) is used in the State of Victoria to assess noise emissions from wind farms. Although the standard was revised in 2010 [5], it is the 1998 version of the Standard that still applies in Victoria. Section 4.3 of the standard recommends the following simple algorithm for prediction of wind farm noise emission:

$$L_R = L_W - 10\log\left(2\pi R^2\right) - \Delta L_a$$

where

L_R = the sound pressure level from a single WTG at 1.2m to 1.5m above local ground *level in dB(A) at distance R*

L_W = *Sound power level of the WTG in dB(A). Measured according to IEA procedures relating to WTG measurement or IEC DIS 61400-11.*

R = the distance between the source and the receiver in metres.

$\Delta L_a = \alpha_a R$

α_a = *attenuation of sound due to air absorption, in dBA/m for broadband sound which is typically 0.005dB(A)/m (refer ISO9613-1). This value is dependent upon the spectral character of the sound and the atmospheric conditions.*

The Standard then goes on to provide the following comments about the methodology:

> *Equation 1 is based on hemispherical spreading of the sound from the source and does not take into account attenuation due to screening effects, i.e. where there is no line of sight between the WTG and receiver locations. Acoustic absorption and reflection effects due to vegetation and ground cover are also ignored....a good estimate can be derived when predicting sound propagation through free space (eg. across open gullies), and a conservative estimate (ie. over-prediction) for propagation across flat locations where ground absorption may be significant.*

Sound power level data

During the planning phase for a wind farm the turbine supplier will provide guaranteed maximum sound power level data for the turbine(s). This will generally comprise:

- A set of A-weighted levels across a range of wind speeds.
- An octave or one-third octave band spectrum, commonly for a single, reference wind speed, to indicate the frequency characteristics of the turbine (the spectral data is often only provided on request and may not be guaranteed).

The spectral data is not strictly required for a prediction according to NZS6808:1998 as the entire routine can be carried out using A-weighted levels only. Indeed, as noted above, it would typically be the case that the A-weighted sound power levels from the manufacturer would be guaranteed whereas the spectral data would not.

However, spectral data can be used for predictions in accordance with NZS6808:1998. The spectral data can also be of use when carrying out predictions using ISO9613-2:1996 *Acoustics – Attenuation of sound during propagation outdoors – Part 2: General method of calculation* (ISO9613-2:1996) as discussed later in the paper.

For Cape Bridgewater Wind Farm, sound power level data is also available from site sound power level measurements carried out according to IEC61400-11:2006 *Wind turbine generator systems – Part 11: Acoustic noise measurement techniques* (IEC61400-11). As could be expected, the measured sound power level data is moderately lower than the guaranteed levels and, arguably, provides a more accurate indication of the actual output of the turbines. Both guaranteed and measured sound power level data is used in this paper.

ISO9613-2:1996

To compare and contrast with the results with the NZS6808:1998 simple algorithm, this paper also presents results of wind farm noise emission predictions using ISO9613-2:1996. The following additional propagation factors, which are explicitly ignored in the NZS6808:1998 algorithm, are considered in the ISO9613-2:1996 model:

- Frequency dependent air absorption
- Ground effect
- Topographical effects of the surrounding landscape, such as shielding

The predictions in this paper use reference atmospheric conditions of 70% humidity, 10°C and 101.325kPa to calculate the frequency dependent air absorption using ISO9613-1:1993 *Acoustics – Attenuation of sound during propagation outdoors – Part 1: Calculation of the absorption of sound by the atmosphere* (ISO9613-1:1993). These atmospheric conditions are comparable to those nominated in several Australian wind farm noise guidance documents [6] [7] [8] where humidity levels of 70-80% and temperatures of 10-15°C are suggested.

Three scenarios have been considered when evaluating ground effects:

- Hard ground, with a ground factor of 0
- Mixed ground, with a ground factor of 0.25
- Mixed ground, with a ground factor of 0.5

Topographical effects have not been considered in the ISO9613-2:1996 model developed for this paper. In other words, the ground is assumed to be flat and level between the turbines and the receiver. It is anticipated that this assumption is reasonable given the flat to gently undulating pastoral land around each wind farm.

NOISE LEVEL MONITORING

Measurement procedure

The methodology recommended in NZS6808:1998 for noise level measurements is generally the same for pre-construction and post-construction noise level measurements. In each case, a logger is placed at a selected residential property adjacent to the wind farm. L_{A95} noise levels are measured continuously over 10 minute intervals for a period of 10-14 days so as to collect at least 1440 data values. Concurrently, 10 minute wind speed data is collected from a suitably located met mast on the wind farm site.

The use of the L_{A95} statistical index is intended to capture the background ambient noise levels, free from effects of brief periods of increased noise such as momentary events, including vehicle pass-by's or a dog bark. Collected data should be reviewed and known or likely extraneous noise levels should be removed, for example, where rain fall data suggests that rainfall has occurred.

The product of either pre-construction or post-construction monitoring will be a data set generally of at least 1440 data pairs, where each pair comprises:

- A 10 minute L_{A95} noise level measurement
- A wind speed measurement for the same 10 minute period

Regression analysis

Section 4.5.5 of NZS6808:1998 requires that background noise measurements be correlated with wind speeds and that a regression curve is to be used to describe the average background noise level versus the wind speed. In practice the regression curve is typically being a 2nd or 3rd order polynomial.

It is the noise levels determined from the regression curve/equation, at integer wind speeds, which are typically used to represent the range of levels that have been measured, particularly for assessment of compliance with noise limits. We shall in this paper refer to such a noise level as the *average noise level*. For example, the *average post-construction noise level at 6m/s* shall refer to the noise level determined from the regression curve/equation through the set of post-construction data pairs, at the integer wind speed of 6m/s.

Derived wind farm noise emission

Section A1.3 *Compliance testing* of NZS6808:1998 states the following:

> [...] *the results of the 'operational' sound measurements should be compared to the background measurements (non –operational) defined by equation A1, to determine compliance. Since the 'operational' measurements will be combined wind farm and background levels, it may be necessary to adjust these measurements to determine the 'wind farm only' levels.*

Despite these comments, NZS6808:1998 does not provide detailed guidance regarding how to correct for background noise. However, Comment C7.5.3 from Section 7.5 *Post-Installation Measurements* of NZS6808:2010 notes the following[1]:

> *While a simple energy subtraction of background and post-installation sound levels is not strictly mathematically correct for L_{90} centile levels, the difference may be taken as the L_{90} wind farm sound levels.*

In practice, despite the time that can elapse between the pre-construction and post-construction monitoring campaigns and the associated likelihood of changes in the ambient noise level during that time, logarithmic subtraction of the average pre-construction noise level from the average post-construction noise level is used to determine the derived level of wind farm noise emission. It is typically the derived level of wind farm noise emission which is compared to noise limits to assess compliance.

It is also worth nothing that the logarithmic subtraction process recommended by the above documents relates to the average pre-construction and post-construction noise levels where, in each case, the levels are derived from a regression curve. Thus, while the origins of the analysis is a set of L_{A95} values, the noise level derived from a regression curve cannot, itself, be strictly considered as a statistical index.

PWEP monitoring campaigns

During the planning phase of the PWEP in 2004-2005, Pacific Hydro carried out pre-construction noise monitoring at properties adjacent to both wind farms for a minimum period of 10 days. They carried out further pre-construction monitoring campaigns at the same set of residential properties at various times throughout a three year period from 2005 to 2008 to collect a more comprehensive set of pre-construction data. This extended set of data is used herein to represent the pre-construction noise environment.[2]

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[1] NZS6808:2010 uses the L_{A90} statistical index in lieu of the L_{A95}. The two indices are broadly comparable and can both be used to quantify the background level of ambient noise. It is understood that NZS6808:2010 adopts the L_{A90} to achieve better consistency with NZS6801:2008.

[2] Refer to Delaire & Walsh (2009) **Error! Reference source not found.** for a review of data collected during the pre-construction monitoring campaigns.

During the initial operating phase for the Cape Bridgewater Wind Farm and for the Cape Nelson South Wind Farm, following commissioning, Pacific Hydro carried out post-construction noise monitoring campaigns. For each wind farm the campaign comprised at least twelve (12) sets of fortnightly monitoring, spaced to occur approximately once a month. Similar to the consolidation of the pre-construction data, the extended set of post-construction data is used herein to represent the post-construction noise environment.

In total, results from 12 monitoring locations were available for analysis across the two wind farms.

COMPARISON OF POST-CONSTRUCTION NOISE LEVELS WITH PREDICTIONS

Coordinating noise levels

The objective of this paper is to gauge the degree of conservatism that is inherent in levels of wind farm noise emission predicted using the simple algorithm from NZS6808:1998. To that end, the following noise levels are available for comparison:

- (A) Predicted L_{Aeq} wind farm noise emission levels
- (B) Average pre-construction noise levels,
  derived from L_{A95} data
- (C) Average post-construction noise levels,
  derived from L_{A95} data, comprising ambient noise and wind farm noise emission.
- (D) Derived wind farm noise levels
  being the logarithmic subtraction of the average pre-construction noise levels from average post -construction noise levels.

Various combinations of the above data sets could be used for comparison. Analytically, the simplest comparison would be the difference, (C) - (A). However, the average post-construction noise levels include influence of ambient noise which is likely to skew the differences that are found with the predicted wind farm noise emission levels. There is also a debatable discrepancy with the noise level descriptors for curve (A) which is calculated as an L_{eq} and curve (C) which is derived from L_{A95} data. While this is not necessarily a major issue, it was deemed preferable to keep noise level comparisons as consistent as possible.

After consideration of various data combinations and differences, the following two sets of noise levels have been compared:

- (A) + (B), the logarithmic sum of the predicted wind farm noise emission and the average pre-construction noise levels, and;
- (C), the average post-construction noise levels.

The advantage of this arrangement is that, during the planning phase, a best estimate of the levels that are likely to be measured at a property once the wind farm is operating, is the logarithmic sum (A) + (B). Accordingly, the sum will be referred to as the *estimated post-construction noise level.*

An inherent drawback of this method is that the predicted levels (A) are in terms of L_{Aeq} while the contribution of wind farm noise emission to the average post-construction noise levels is recorded as an L_{A95}. One means of overcoming this issue would be to estimate the L_{A95} predicted noise levels from the L_{Aeq} values. However, it was felt that the additional uncertainty that this may introduce into the analysis would not be justified in terms of any potential gains in accuracy. Therefore, the method outlined above has been used and readers should be aware of the potential inconsistency across noise level descriptors.

NZS6808:1998 predictions

Figure 2 below presents the analysis carried out for one of the twelve monitored sites. It can be observed that:

- The estimated post-construction noise level, being the logarithmic sum (A) + (B), is shown in black.
- The average post-construction noise level curve (C) is shown in red.
- The scatter of noise level and wind speed data pairs collected during the post-construction monitoring campaign are also included, in green, for information.

These predictions use guaranteed sound power level data for the turbines and an A-weighted air absorption coefficient of 0.0023dBA/m [3] in lieu of the 0.005dBA/m value suggested in NZS6808:1998.

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[3] 0.0023 dB/m has been the absorption coefficient used for wind farm noise emission predictions for PWEP during the various planning processes and, for continuity, is therefore also used in this paper.

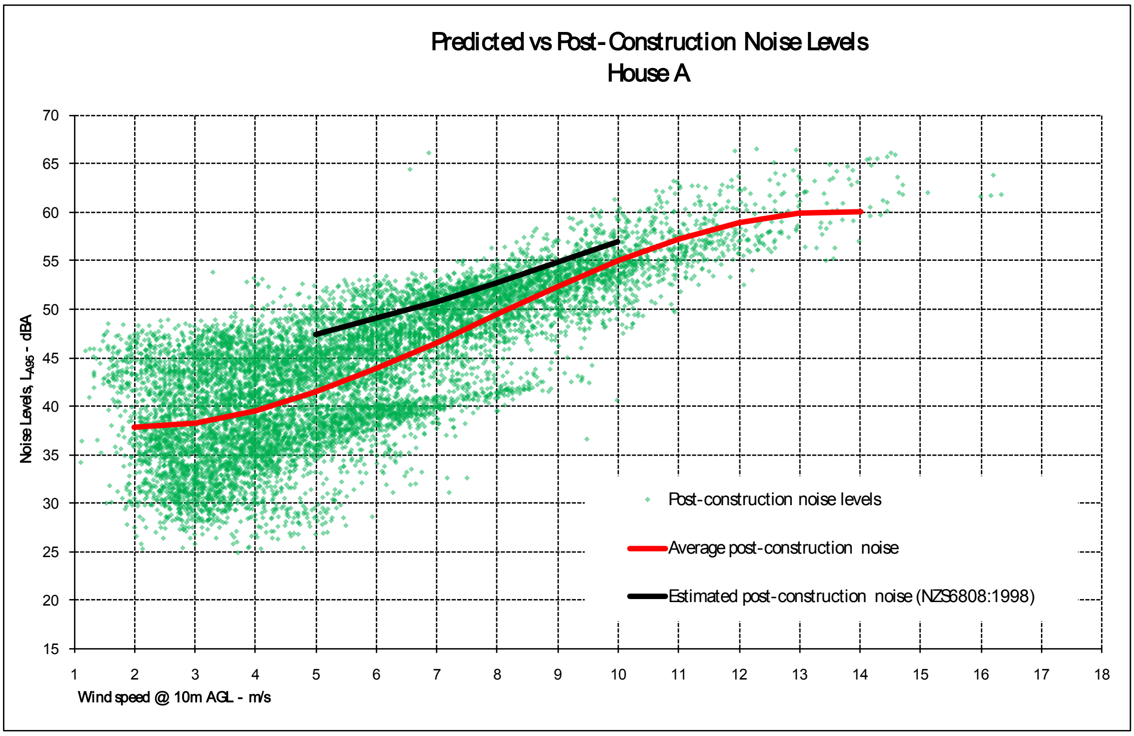

Figure 2: Comparison of average and estimated post-construction noise levels (NZS6808:1998)

A complete set of figures is included in Appendix A. Table 1 below presents a summary of the arithmetic differences between the average and estimated post-construction noise levels across the range of assessed wind speeds. In other words, for each property analysed, it shows the difference at each integer wind speed between the black and red curves.

Table 1: Summary of comparison of average and estimated post-construction noise levels (NZS6808:1998)

House	**Wind speed at 10m AGL (m/s)**					
	5	**6**	**7**	**8**	**9**	**10**
A	6	5	4	3	3	2
B	1	1	1	1	1	2
C	4	4	3	4	4	4
D	5	6	5	5	5	4
E	4	3	3	2	1	1
F	1	2	2	2	2	3
G	3	5	5	4	3	2
H	2	4	4	2	1	1
I	2	4	4	3	1	1
J	5	4	3	2	1	1
K	4	5	5	4	4	3
L	5	5	4	3	2	1
Average	**3.5**	**4.0**	**3.6**	**2.9**	**2.3**	**2.1**
Standard deviation	**1.7**	**1.4**	**1.2**	**1.2**	**1.4**	**1.2**

As shown in the table, the NZS6808:1998 simple prediction algorithm results in over-predicting average post-construction noise levels by 1-6dBA. The average level of over prediction ranges from 2.1-4dBA. Note that this conclusion is based on the use of guaranteed sound power level data.

Adjusting the air absorption coefficient from 0.0023dBA/m to 0.005dBA/m, the value suggested in NZS6808:1998, will decrease predicted levels of wind farm noise emission. The decrease will generally be in the order of 2-4dB depending on the relative distance of the turbines from the receiver. Table 2 below presents the same summary of differences as shown in Table 1 above with the exception that predicted levels use an air absorption coefficient of 0.005dB/m.

Table 2: Summary of comparison of average and estimated post-construction noise levels (NZS6808:1998), air absorption coefficient of 0.005dB/m

House	**Wind speed at 10m AGL (m/s)**					
	5	**6**	**7**	**8**	**9**	**10**
A	5	5	4	3	2	2
B	0	0	0	0	1	1
C	2	2	2	2	2	2
D	3	3	3	3	3	2
E	2	1	0	0	0	-1
F	0	1	1	1	2	2
G	1	3	3	2	1	1
H	0	2	1	1	0	-1
I	0	2	1	0	0	-1
J	2	2	1	0	0	0
K	2	4	4	3	2	2
L	3	2	2	1	0	0
Average	**1.3**	**1.7**	**1.4**	**1.0**	**0.7**	**0.7**
Standard deviation	**1.9**	**1.7**	**1.5**	**1.3**	**1.2**	**1.2**

As shown in the table, average post-construction noise levels are over-estimated by -1-5dBA. The average level of over prediction ranges from 0.7-1.7dBA. Adjusting the air absorption coefficient from 0.0023dBA/m to 0.005dBA/m therefore generally improves agreement between the average and estimated post-construction noise levels. However it should be noted that at three of the monitored properties the estimated post-construction noise levels under-predict the average post-construction noise levels – a circumstance which would typically be undesirable during the planning phase of a wind farm. Moreover, the monitoring sites are generally 500-1000m from the closest turbine and at this moderate distance the effect of the atmospheric absorption coefficient is, in relative terms, less. At greater distances from the nearest turbine, the effect of the 0.005dBA/m coefficient will become greater and could results in some very significant under-prediction of actual noise emission levels.

ISO9613-2:1996 predictions

The ISO9613-2:1996 prediction algorithms allow consideration of ground effect and frequency dependent air absorption into the predicted wind farm noise emission levels. Assumed atmospheric conditions are detailed above. Results presented here use a ground factor of 0.5.

Figure 3 below presents a similar analysis to that presented above for NZS6808:1998, using ISO9613-2:1996 predicted levels to derive the estimated post-construction noise levels which are shown by the black, dashed curve.

For this series of predictions, guaranteed sound power level data has been used.

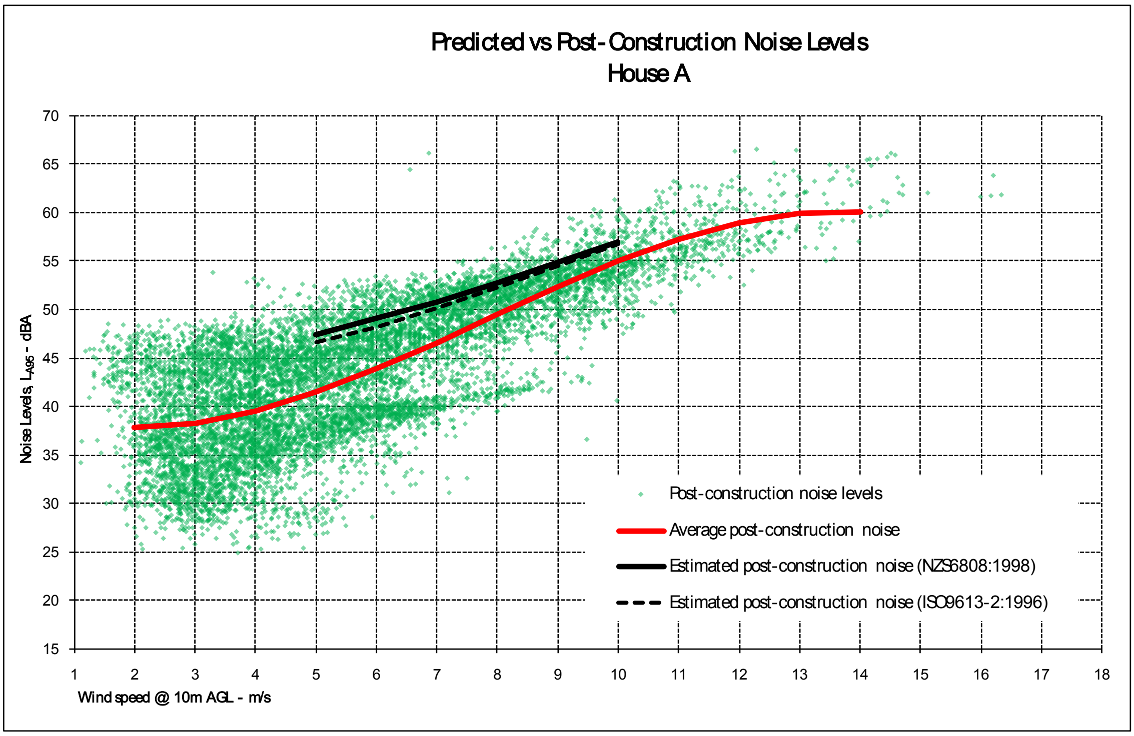

Figure 3: Comparison of average and estimated post-construction noise levels (ISO9613-2:1996)

A complete set of figures in included in Appendix A. Table 3 below presents a summary of the arithmetic differences between the average and estimated post-construction noise levels across the range of assessed wind speeds.

Table 3: Summary of comparison of average and estimated post-construction noise levels (ISO9613-2:1996)

House	Wind speed at 10m AGL (m/s)					
	5	**6**	**7**	**8**	**9**	**10**
A	5	4	4	3	2	2
B	-1	0	0	0	1	1
C	1	1	1	1	1	2
D	3	3	3	3	3	2
E	1	0	0	-1	-1	-1
F	0	1	1	1	1	2
G	1	2	2	1	1	1
H	0	1	1	0	0	-1
I	0	1	1	0	-1	-1
J	2	2	1	0	0	0
K	2	3	3	2	2	1
L	1	0	0	-1	-1	-1
Average	1.3	1.7	1.4	1.0	0.8	0.7
Standard deviation	1.7	1.4	1.2	1.1	1.1	1.2

As shown in Table 3, the ISO9613-2:1996 prediction algorithm with frequency dependent air absorption and a ground factor of 0.5 results in over-predicting average post-construction noise levels by 0-5dBA. The average level of over prediction ranges from 0.8dBA to 1.7dBA. Note that this conclusion is based on the use of guaranteed sound power level data.

Average level differences for a range of ISO9613 predictions, determined by varying the ground factor, are summarised in Table 4 below.

Table 4: Variation in noise level differences by varying the ISO9613-2:1996 ground factor

Scenario	Average difference between average and estimated post-construction noise levels Wind speed at 10m AGL (m/s)					
	5	6	7	8	9	10
Ground factor 0.5 (Base case)	1.3	1.7	1.4	1.0	0.8	0.7
Ground factor 0.25	2.3	2.8	2.4	1.9	1.5	1.3
Ground factor 0	3.6	4.2	3.7	3.1	2.4	2.0

As shown in Table 4, the ISO9613 prediction algorithm with frequency dependent air absorption and a ground factor of 0 results in a 2-3 fold increase in the over-prediction of average post-construction noise levels compared to the case of a ground absorption coefficient of 0.5.

Note that the above comparisons use guaranteed sound power level data to determine the estimated post-construction noise level. The degree of conservatism inherent in this data is not known but it anticipated to be in the order of 1-2dBA.

Measured wind turbine sound power level data was available for the Cape Bridgewater Wind Farm turbines. This data has been used to calculate the estimated post-construction noise levels for the seven monitored properties adjacent to the wind farm. The average and standard deviation of the noise level difference between the average and estimated post-construction noise levels for these seven properties is detailed in Table 5. A ground factor of 0.5 has been used.

Table 5: comparison of average and estimated post-construction noise levels (ISO9613-2:1996), measured SWL data

Scenario	Average difference between average and estimated post-construction noise levels Wind speed at 10m AGL (m/s)					
	5	6	7	8	9	10
Average level difference	0.4	1.0	1.2	0.6	0.0	0.3
Standard deviation	2.2	1.8	1.5	1.4	1.4	1.2

Using the measured sound power level data tends to result in over-predicting average post-construction noise levels by 0-1.2dBA and seems to provide the best agreement of the various ISO9613 prediction arrangements considered.

UNCERTAINTY

There is uncertainty in both the measured noise level data used in this analysis and the prediction algorithms used.

Prediction accuracy

NZS6808:1998 does not provide any explicit discussion of the accuracy or uncertainty of its recommended prediction algorithm. However, the fundamental approach of the algorithm, being geometric divergence, is similar to that used by ISO9613-2:1996 where the later standard does include a discussion of accuracy.

Specifically, ISO9613-2:1996 estimates an average accuracy of ±3dB for source heights less than 30m and receiver distances of less than 1000m, with moderate downwind conditions. These conditions often don't apply to wind farms where the source height will generally be much greater than 30m, the separation distance will often be more than 1000m and the wind speed and direction can vary greatly over the duration of the monitoring period. Accordingly, it could be anticipated that an average accuracy of more than ±3dB is likely.

However, a study by Bass, Bullmore and Sloth [11] found that for flat, rolling and complex terrain sites ISO9613-2:1996 predicted noise levels to within 1.5dBA accuracy of levels measured under conditions of an 8ms^{-1} positive wind vector.

A study conducted by Hoare Lea Consulting Engineers [12] compared predicted levels using ISO9613-2:1996 to measured levels at four receiver locations between 100 – 800m distance from an operational UK wind farm. The downwind measurements used in the comparison were between +/- 15 to 45 degrees, with hub height wind speeds of 8-14 ms^{-1}. Two ground factors were modelled, a hard ground assumption (G=0) and a mixed ground assumption (G=0.5). Results from the study indicated that when considering worst case downwind directions of +/- 45 degrees from the direct line between source and receiver, ISO9613-2:1996 predicted levels approximately 1-2 dBA higher than measured levels at the farthest measurement location. Where the wind direction angle was limited to downwind +/- 15 degrees, ISO9613 predicted levels up to 3dBA higher than measured levels, up to 13ms^{-1}. However, it was noted that as distance from source to receiver increased, the comparative difference decreased, until at the farthest measurement position, predicted and measured levels were equal. This trend could be attributed to the increasing contribution of background noise to overall noise level as a function of distance.

The results of these studies suggest that the ±3dB average accuracy range of the ISO9613-2:1996 prediction model may indeed also be valid for the source/receiver arrangements for wind farms.

Measurement uncertainty

There are a range of factors which contribute to the uncertainty in the measurements, including the passage of time between the pre-construction and post-construction noise monitoring campaigns. Also, there are uncertainties associated with the collection of wind data, which occurs over a range of heights and has involved different met masts, in different locations, throughout the duration of the monitoring campaigns.

Not least of the uncertainties is that of the meters used to carry out the monitoring. Type 2 meters were used, with an uncertainty of approximately ±1.5dB.

Discussion

Given the range of uncertainties associated with the analysis, any agreement between the average and estimated post-construction noise levels of better than 1.5dBA, that is with a difference of less than 1.5dBA, may be considered as a good level of agreement.

CONCLUSION

Long term, unattended pre-construction and post-construction noise monitoring data has been used to quantify the degree of conservatism that results from using a two wind farm noise emission algorithms, NZS6808:1998 and ISO9613-2:1996, with a number of different parameter arrangements.

Using the comparison of the average post-construction noise levels with the estimated post-construction noise levels, as these terms are defined above, an average level of over-prediction has been calculated.

For the NZS6808:1998 predictions algorithm, the average over prediction ranges from approximately 2-4dBA for the modelling assumptions detailed. For the ISO9613-2:1996 algorithm, the average over prediction is less, and ranges from approximately 1.5-2dBA for the assumptions detailed.

Moreover, for the wind farms considered by this paper, a ground factor of 0.5 resulted in the best agreement with measured data, compared to ground factors of 0.25 and 0. The absence of a ground factor in the NZS6808:1998 simple prediction method is a significant source of conservatism for the source to receiver arrangements at PWEP.

Further, using measured wind turbine sound power level data in lieu of guaranteed levels also further improved agreement with measurements.

Appendix A

Analysis using NZS6808:1998 and ISO9613-2:1996 prediction algorithms

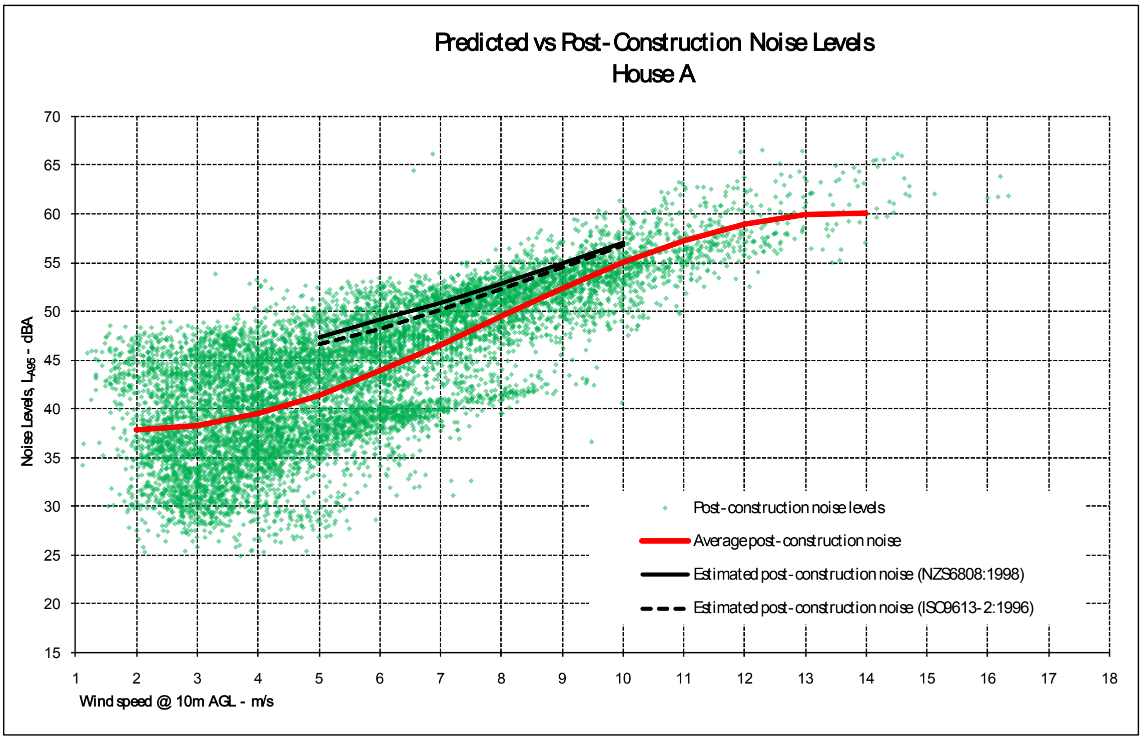

Figure 4: House A comparison of average & estimated post-construction noise levels

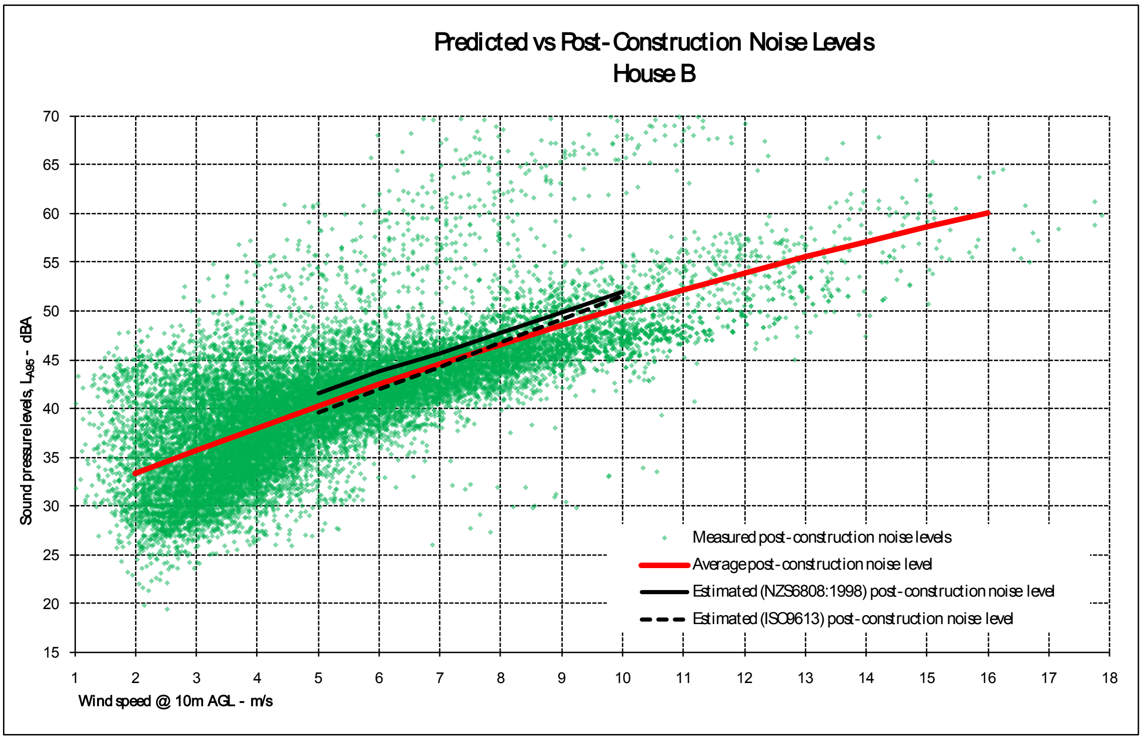

Figure 5: House B comparison of average & estimated post-construction noise levels

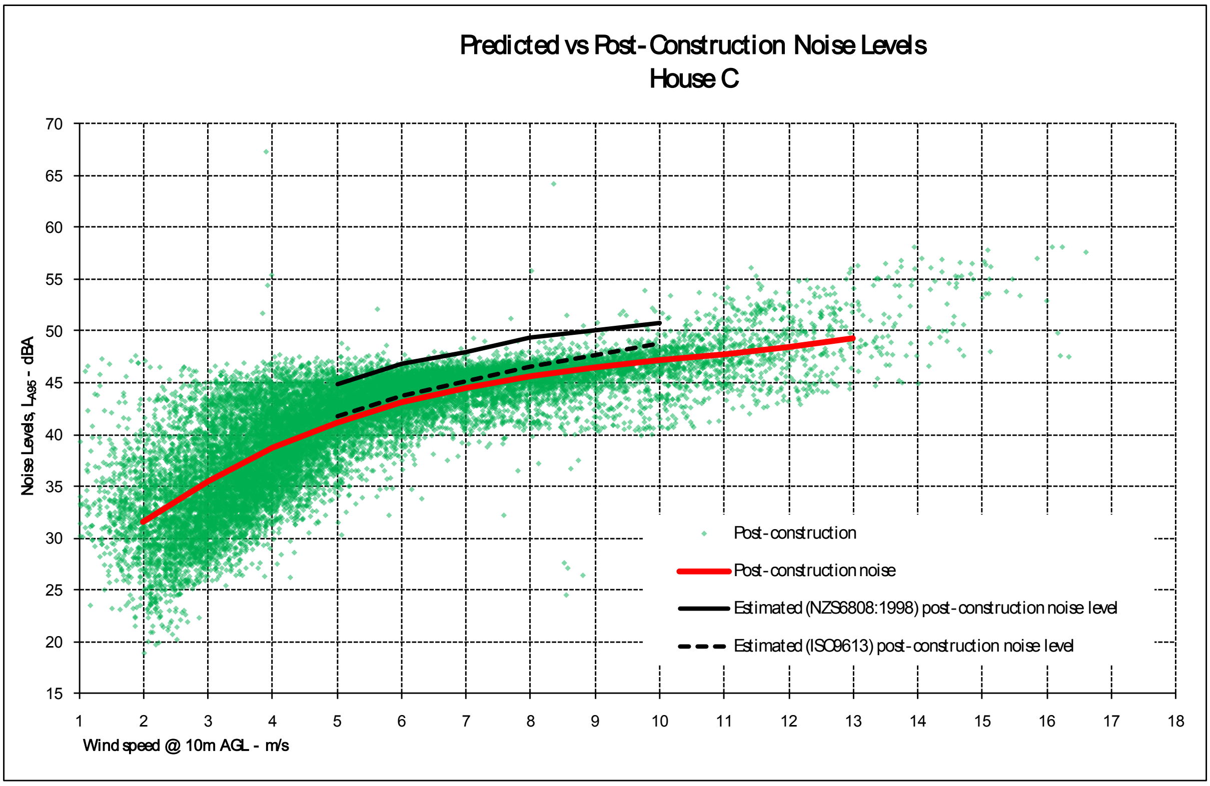

Figure 6: House C comparison of average & estimated post-construction noise levels

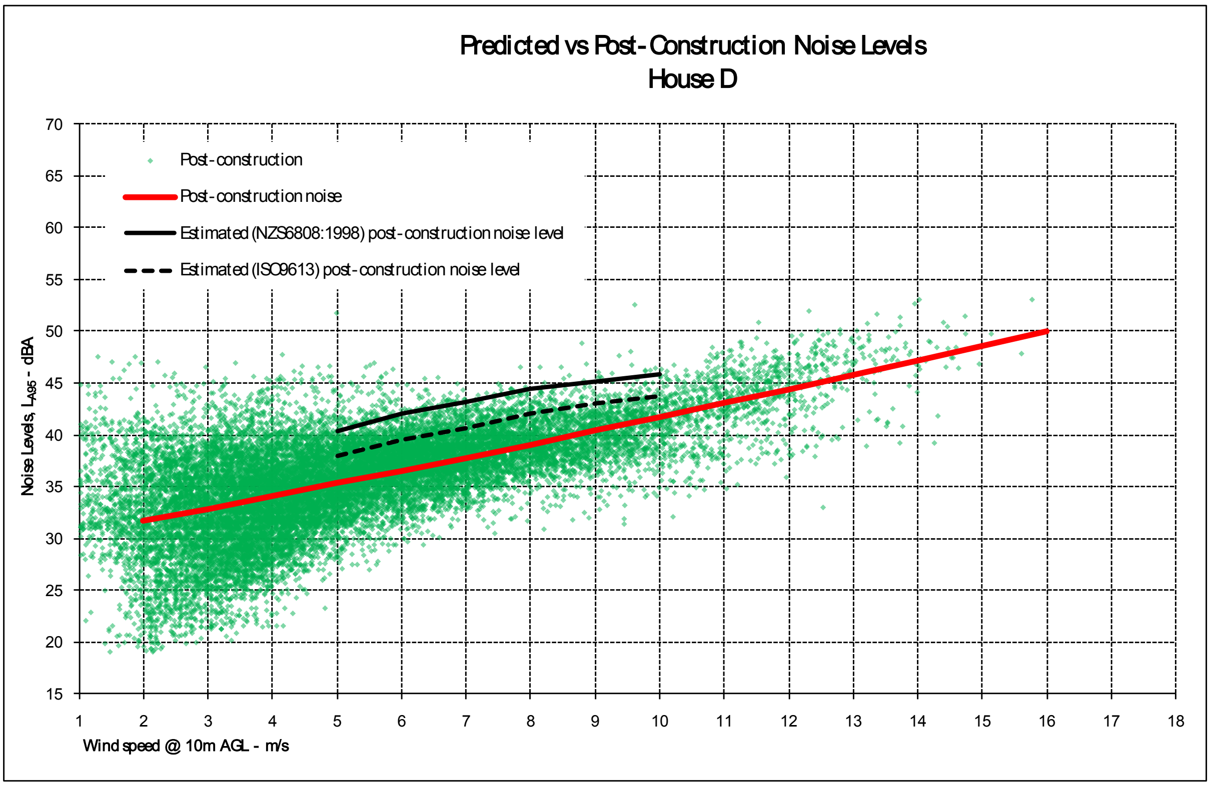

Figure 7: House D comparison of average & estimated post-construction noise levels

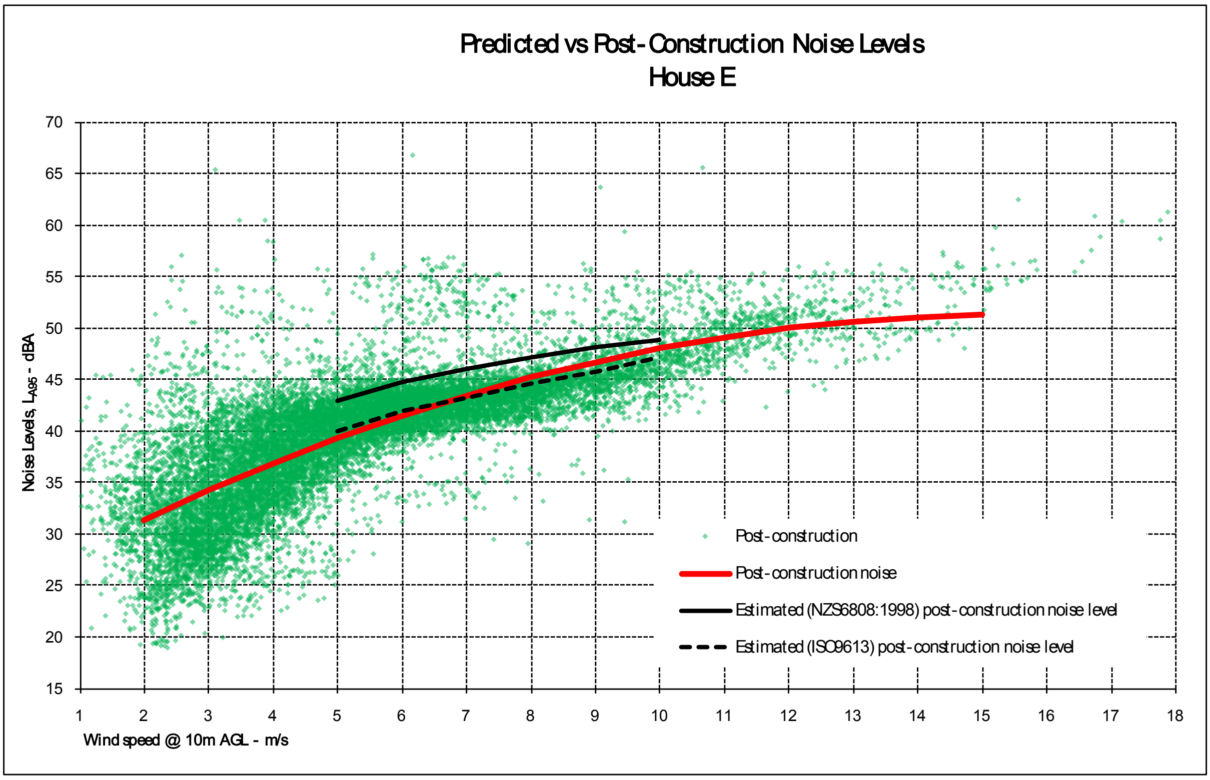

Figure 8: House E comparison of average & estimated post-construction noise levels

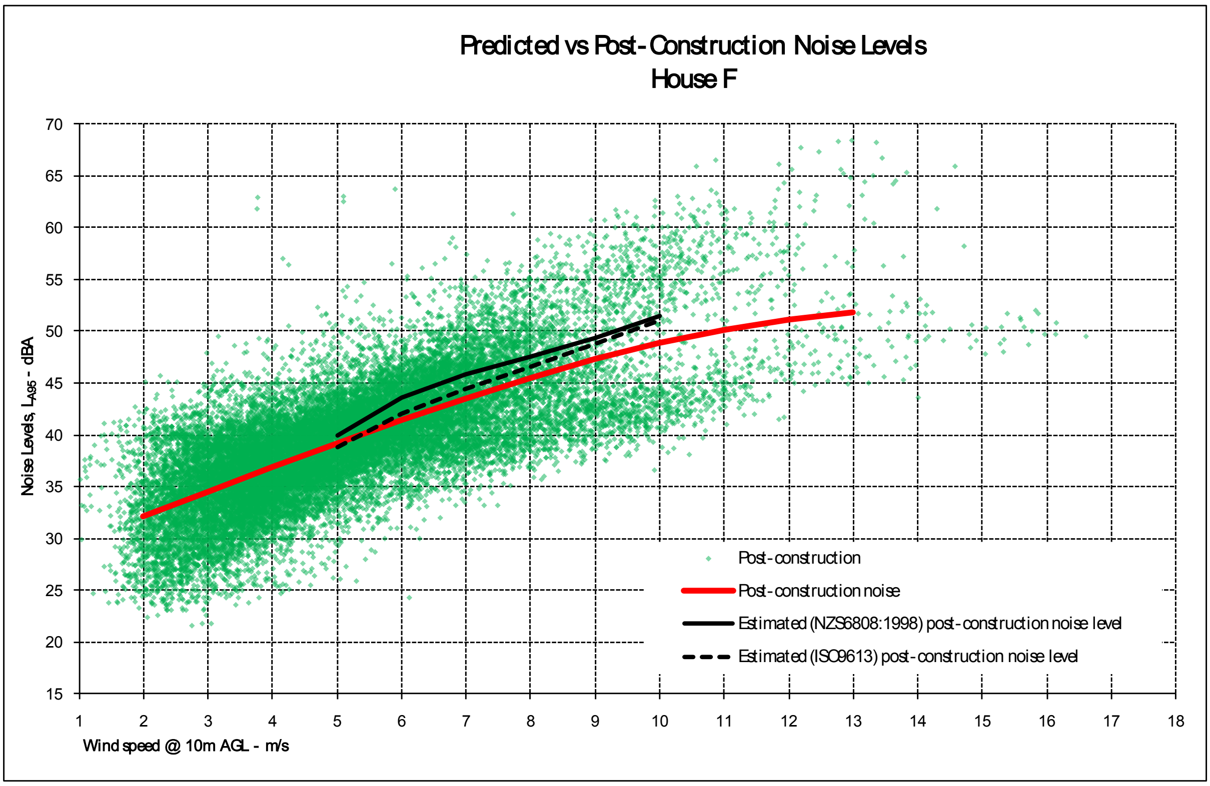

Figure 9: House F comparison of average & estimated post-construction noise levels

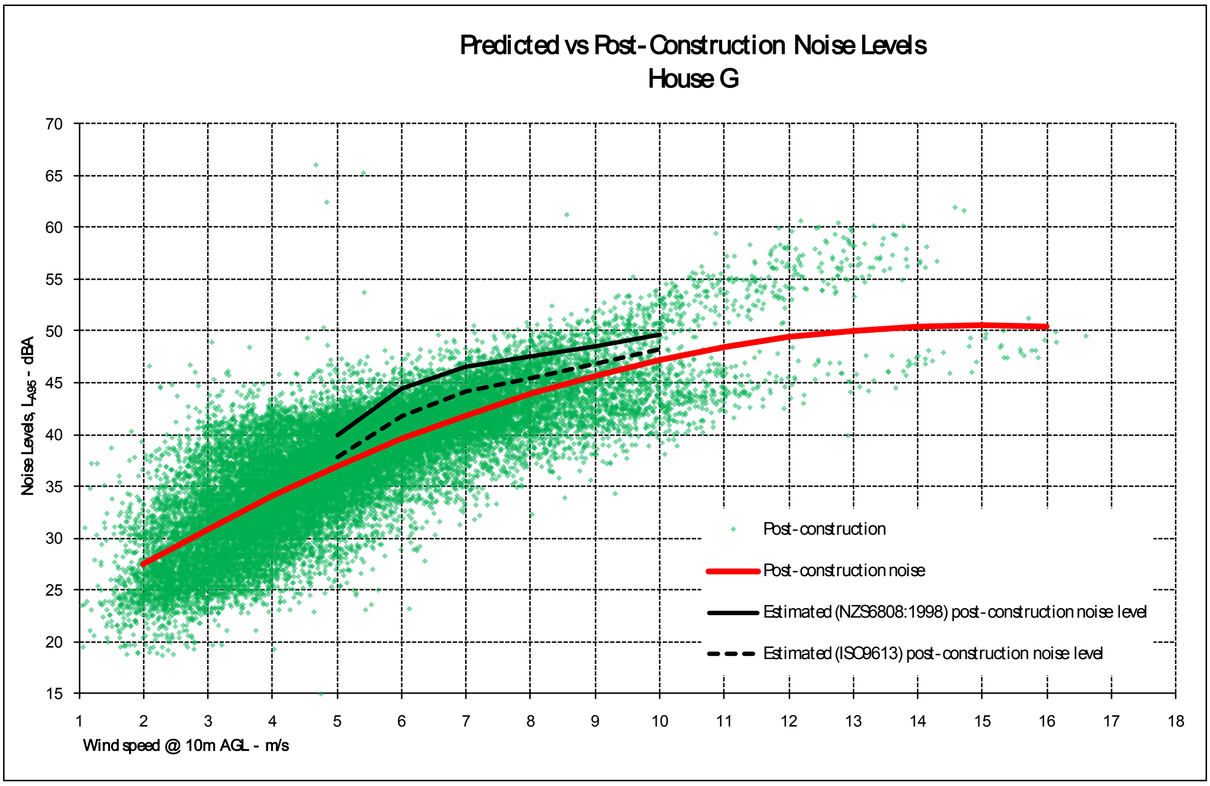

Figure 10: House G comparison of average & estimated post-construction noise levels

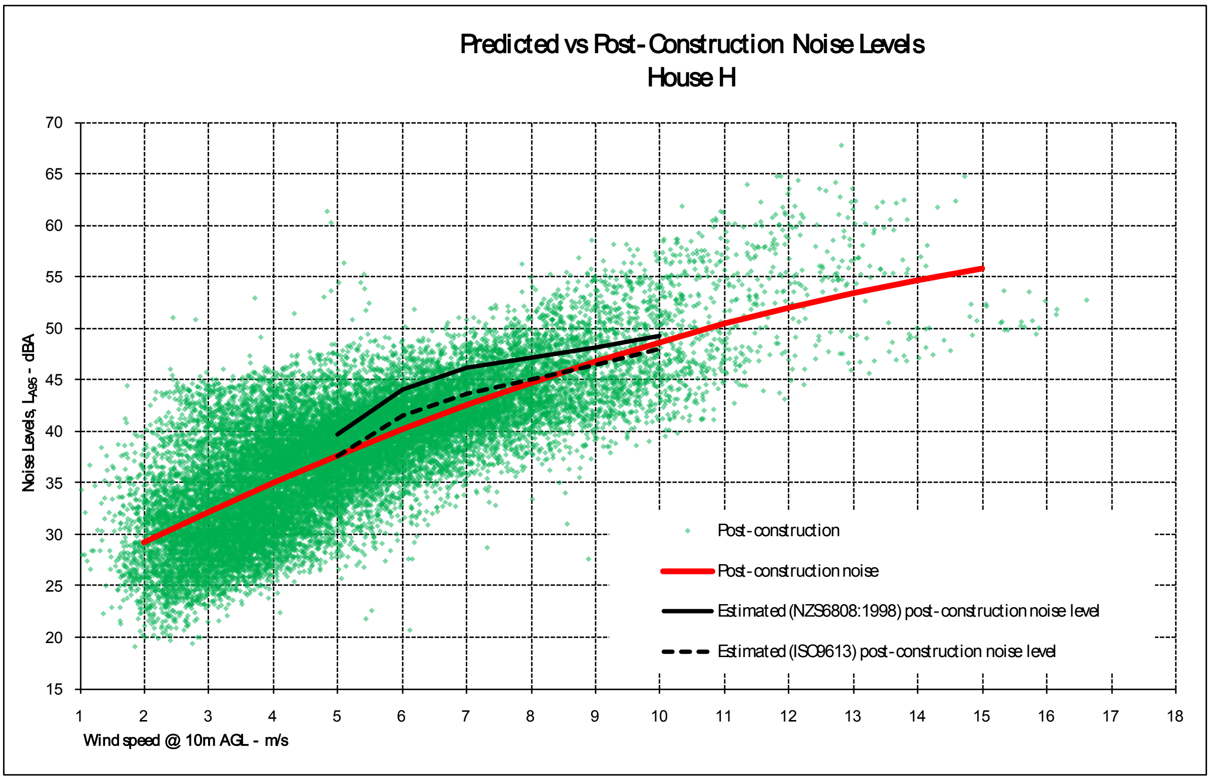

Figure 11: House H comparison of average & estimated post-construction noise levels

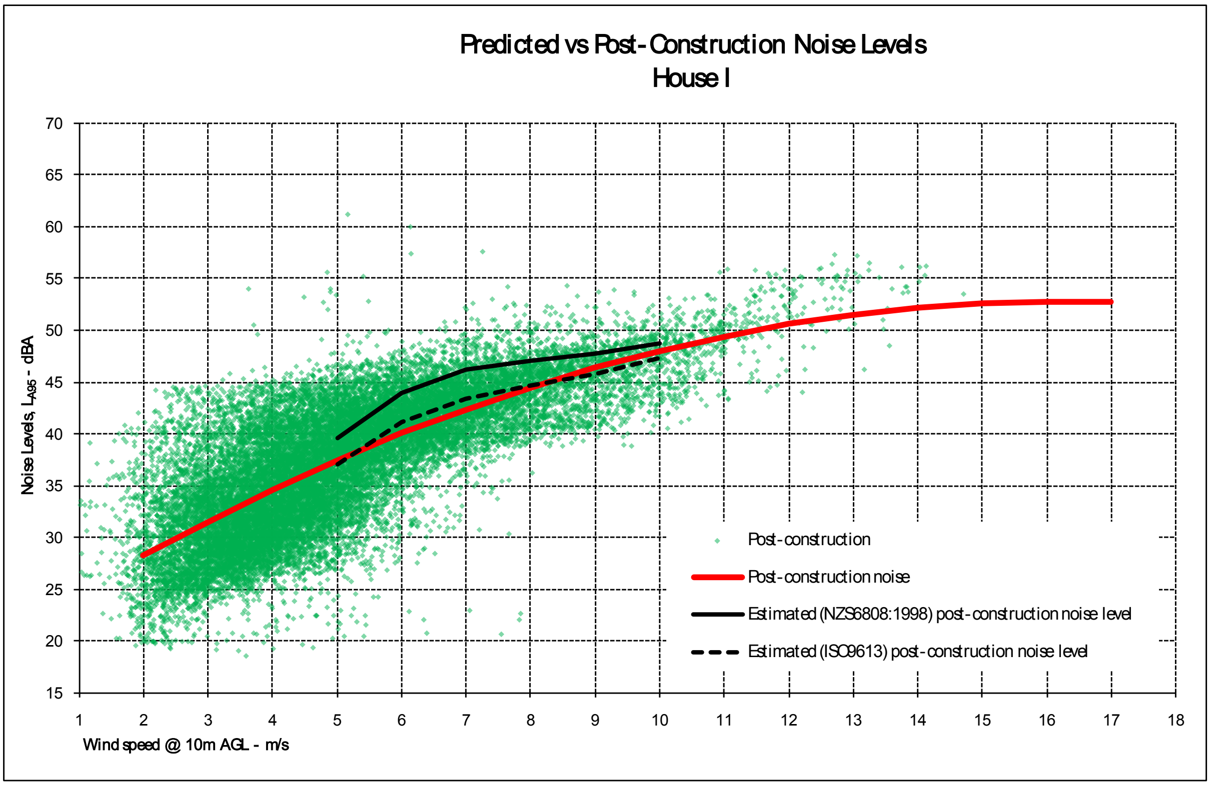

Figure 12: House I comparison of average & estimated post-construction noise levels

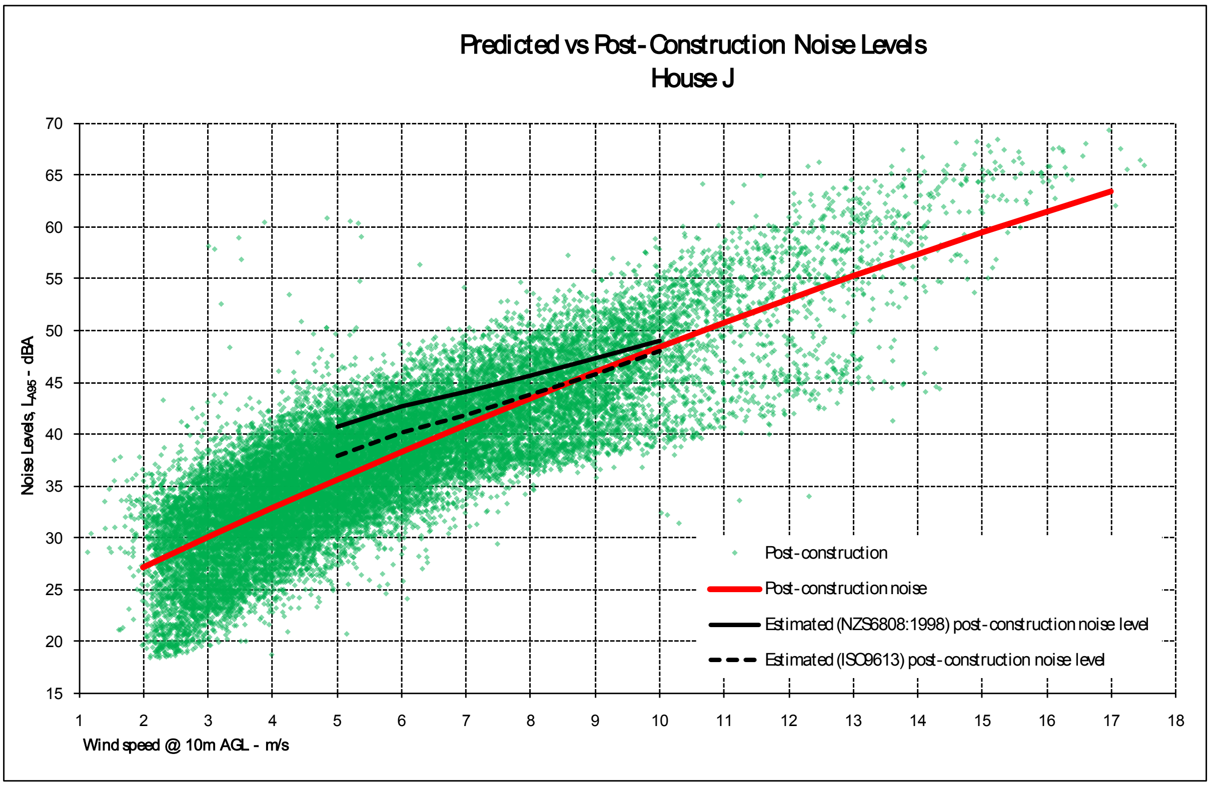

Figure 13: House J comparison of average & estimated post-construction noise levels

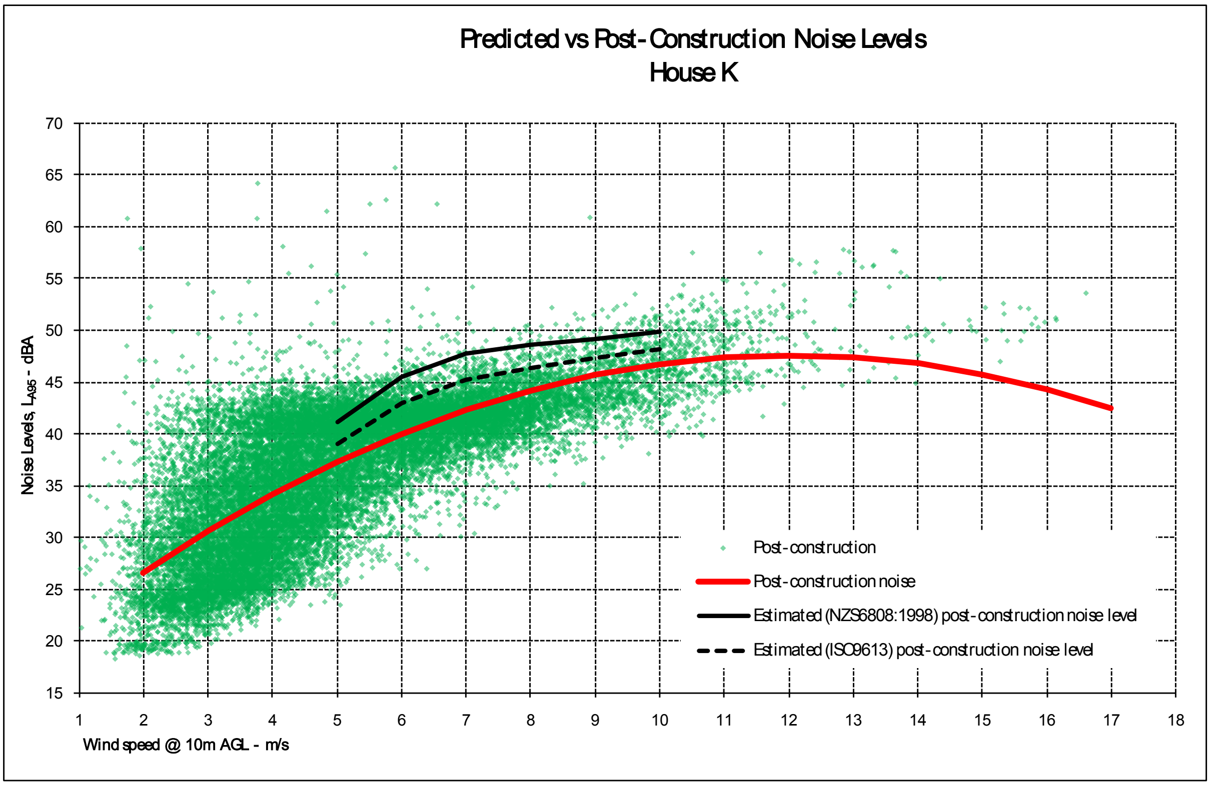

Figure 14: House K comparison of average & estimated post-construction noise levels

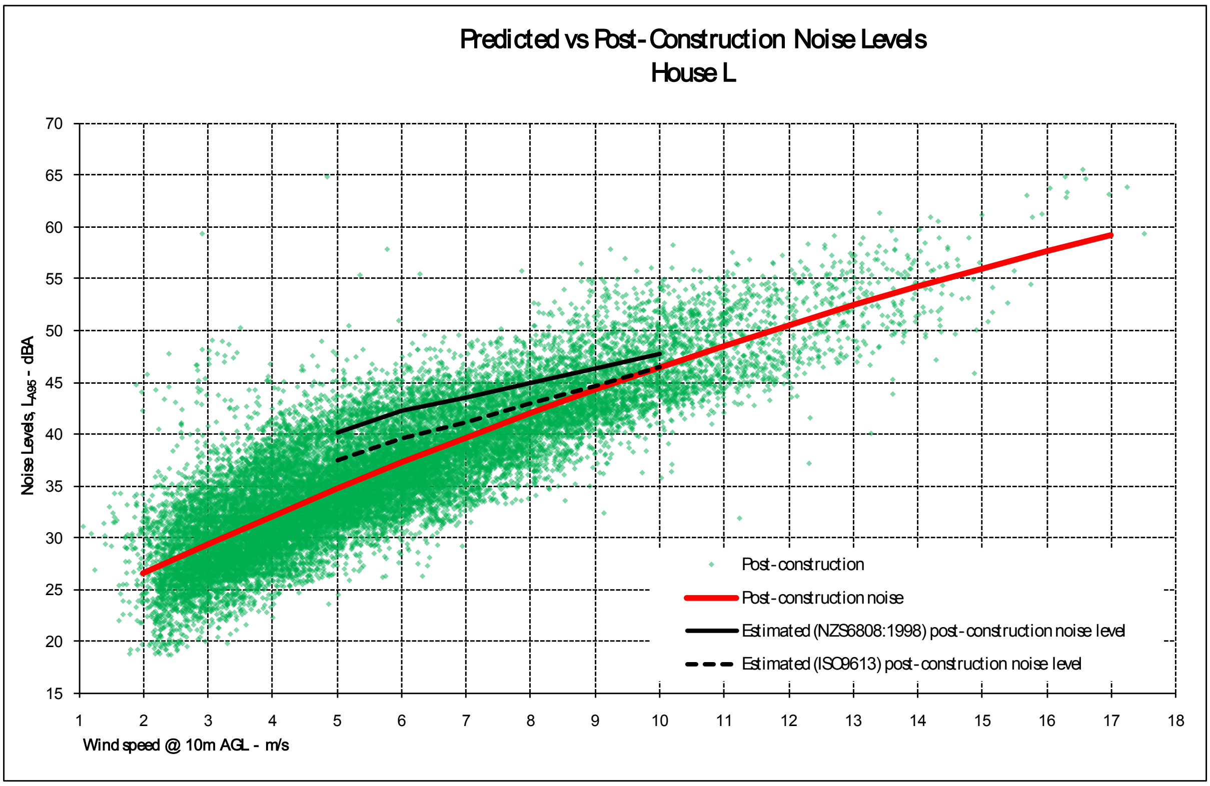

Figure 15: House L comparison of average & estimated post-construction noise levels

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