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Urban wind turbines

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ABSTRACT

Acoustic assessment methods for wind turbines and wind farms in rural areas of Australia have grown to be well established in recent years. Guidance documents such as New Zealand Standard NZS6808 and *Environmental Noise Guidelines: Wind Farms* published by the South Australian EPA provide clear guidance on how to assess noise from wind turbines and the noise limits which should apply to them. But these guidance documents have generally been developed for application to rural areas where the turbines are located several hundred metres, if not kilometres away from the nearest residential dwelling. The assessment of wind turbines in urban and city environments involves several factors which are absent in the rural context such as a higher background noise level, potentially more variability of background noise level with time of day and day of the week, closer proximity of residential dwellings and the potential for residential dwellings to share common structural elements with the wind turbine. Given these factors, this paper investigates the suitability of existing wind turbine noise guidance documents and other applicable guidance documents.

INTRODUCTION

The *Policy and planning guidelines for development of wind energy facilities in Victoria*, 2003 requires:

> An assessment of the noise impact of the proposal on existing dwellings prepared in accordance with New Zealand Standard NZ6808:1998, Acoustics—The Assessment and Measurement of Sound from Wind Turbine Generators. (Sustainable Energy Authority Victoria 2003: 21)

The use of NZS6808 as an assessment method is reasonably well established for large scale industrial wind farms, typically 30MW or bigger, in rural areas of Victoria.

However, it is not clear at this stage whether the guidelines should apply to smaller scale wind turbines in urban areas or if some other guidelines would be better suited. In fact, as small, urban wind turbines have been so rarely installed to date, there is no clearly established assessment method for noise and vibration emissions.

It is possible that the use of small, urban wind turbines will increase in the future with improvements in technology and as people look to diversify their energy production methods. In such a case, some kind of noise assessment method will be required by councils and regulating authorities in order to determine suitable planning requirements.

There are a number of considerations, such as wind speed and noise variation with altitude, which are particular to the assessment of noise emissions from wind turbines. While these issues are well addressed in NZS6808 and other guidance documents for large wind farms, there are several further considerations specific to small, urban wind turbines which are not addressed by these documents. These include close proximity of neighbours, the potential for structure borne noise and vibration radiation and the potential need to assess noise levels indoors.

A brief discussion of these issues is provided below. It should be noted that this paper is intended as a discussion document only and is neither a comprehensive review of applicable criteria nor a formal evaluation of any future criteria.

In this paper the term Urban Wind Turbine (UWT) will be used to refer to small wind turbine generators with a swept area of less than 200m^2, which are intended for use in urban areas. Wind Turbine Generator (WTG) will be used to refer to large wind turbines with a swept area of greater than 200m^2. Vibration issues related to the operation of an UWT will not be considered in this paper.

CHARACTERISTICS OF WIND TURBINES

Operating speeds

A wind turbine is noisiest only under certain wind conditions. When wind speeds are low the turbine does not operate and there is minimal wind turbine noise. When wind speeds are high natural noise due to wind in the environment is often louder than the turbine. It is typically only at mid-range wind speeds that a wind turbine usually becomes audible above the background noise level.

It is for this reason that wind turbine specific guidance documents such as NZS6808 recommend noise limits based on

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both background noise level and wind speed. Concurrently, it limits the usefulness of many general guidance documents for noise control which often require neutral weather conditions for assessment of noise emissions, with a wind speed of 5m/s or less.

The average wind speed in urban areas is typically less than in rural areas (Alternative Technology Association 2007) so that UWT's which are able to operate at lower wind speeds may therefore have an advantage in terms of energy production (WINEUR 2005). This means that UWT's may have the potential ability to generate significant noise levels at low wind speeds during which time the background noise level from wind induced noise is likely to be low.

Tonality

Depending on the turbine model and the operating wind speed, noise emissions from wind turbines can be considered tonal. An assessment of tonality is therefore required for each different wind turbine model considered for installation. If a wind turbine is considered tonal a 5dB penalty is typically applies to the noise assessment, making it more difficult to comply with noise limits. Many WTG manufacturers provide guarantees that their WTG's are not tonal.

RURAL WIND TURBINES

Applicable standards

Applicable standards relating to the measurement and assessment of WTG’s in rural areas include:

- New Zealand standard: Acoustics – The assessment and measurement of sound from wind turbine generators (NZS 6808:1998)
- EPA SA Environmental noise guidelines: wind farms
- Draft Australian Standard: Acoustics – Measurement, prediction and assessment of noise from wind turbine generators (DR07153 CP)

Overview of wind turbine assessment methods

Assessment of noise impact from WTG’s in rural areas generally follows a common approach involving the following steps:

- Predict WTG noise levels at surrounding residential locations to determine whether predicted noise levels are expected to be less than some base line noise level (for example, the base line noise level for NZS6808 is 35dBA).
- For those critical properties where WTG noise is predicted to exceed the base noise limit, carry out medium term background noise monitoring
- Correlate background noise monitoring data with time-synchronised wind data from hub height of the proposed WTG’s.
- Determine a noise limit curve for each critical residence, using a background noise level curve, obtained from a regression analysis, which describes the variation in background noise level with variations in wind speed.
- Apply corrections as necessary for tonality
- Compare the noise limit curve with predicted WTG’s noise levels across the same range of wind speeds to determine whether compliance with the noise limits is achieved

The key acoustic point in this assessment method is that background noise level is determined as a function of wind speed and, in turn, noise limits are also set as a function of wind speed.

It is also worth noting that some WTG guidance documents prescribe minimum distances between a WTG and the nearest residential dwelling as a means of noise control.

URBAN WIND TURBINES

Special factors

For the assessment of UWT's it would seem sensible to adopt an approach similar to that used for rural wind farms and WTG's. However, assessment of noise from UWT's involves several factors which are unique to small turbines and the urban environment. These are discussed below.

Higher background noise levels

It is commonly considered that background noise levels in urban areas are higher than in rural areas. Examples of background noise level monitoring in rural and urban areas are discussed here to further investigate this notion.

Figure 1 below shows three examples of noise monitoring in rural areas, for a period of about 7 days. Variations in noise level over timer are primarily due to weather conditions and human activity. All of the monitoring data was measured during the same period of the same year, in autumn. The data may not reflect noise variations due to season or year.

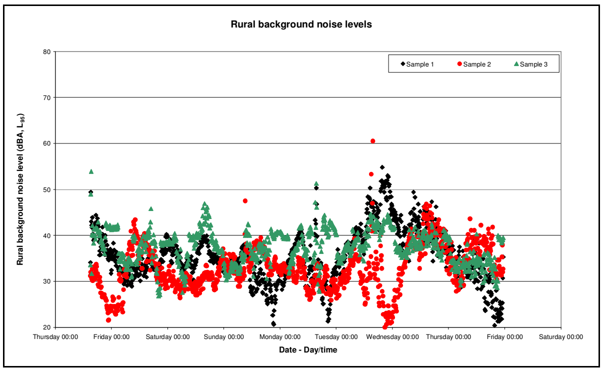

Figure 1 Three samples of background noise level monitoring in rural areas

These examples are not intended to be representative of all rural background areas, but they do provide an indication of what background noise levels can be expected.

Figure 2 below shows three examples of noise monitoring in urban areas in the centre of Melbourne, in the Docklands, North Melbourne and the CBD. Monitoring was carried out for a period of about 7 days in each case.

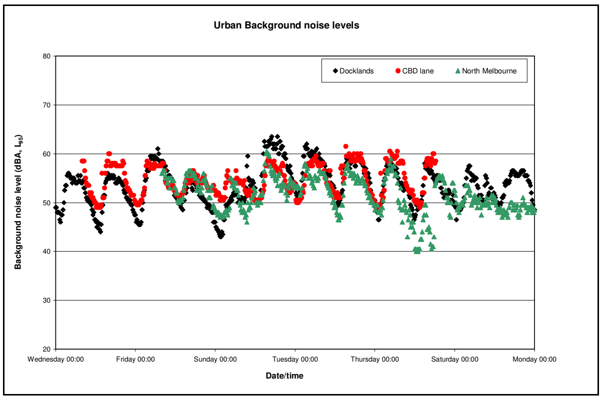

Figure 2 Three sampels of background noise level monitoring in urban areas

These examples are not intended to be representative of the background noise level in all urban areas but they do provide an indication of what background noise levels can be expected.

The logarithmic average of the three rural measurements and the logarithmic average of the three urban measurements are plotted in Figure 3 below.

As can be seen, the average background noise level for the urban data is significantly higher than the average background noise level for the rural data. While this comparison of just six data sets should by no means be considered conclusive, it does agree will with expectations that noise levels in urban areas are generally higher than in rural areas.

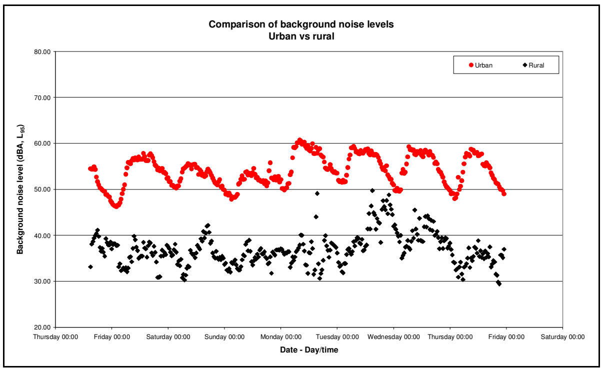

Figure 3 Comparison of background noise level data in rural and urban areas

Background noise level variation with wind speed

It is commonly considered that the background noise level in urban areas is less correlated with wind speed than in rural areas. This is likely due to two factors:

- Average wind speeds in urban areas are generally less than in rural areas
- Other urban noise sources such as traffic, tram and train noise significantly influence the background noise level in urban areas.

The background noise levels plotted in Figure 2 are generally consistent with this notion. As can be seen, variations in noise level are periodic and are heavily influenced by human activity and traffic noise. Background noise levels are lowest during the early hours of the morning on each day, when the noise level is up to 10dB quieter than during peak rush hour periods. Background noise levels also appear to be generally quieter during weekends and are expected to be less dependent on wind speed.

Irregularities at high wind speeds

Small wind turbines which have been developed in the past have generated strong tonal noise or other audible characteristics at high wind speeds (Renewable Energy Research Laboratory, 2006). These characteristics can be loud enough to cause significant annoyance even in the elevated background noise environment that would coincide with the wind speeds required to generate them.

While it may be possible in the future to engineer these irregularities out of the UWT's, it emphasises the importance of developing a criterion which recognises the effect of tonal noise and the variation of noise level with wind speed.

Assessment position

Standards such as NZS6808 specify assessment locations outside of, but near to residential dwellings. These external assessment locations are suitable for residential dwellings located far from the wind turbines and also for balconies and decks of all residential dwellings. However, assessment locations within dwellings may be required where a dwelling shares common structural elements with the wind turbine such as if a turbine is installed on the roof top of a residential apartment.

Assessment of future dwellings at elevated positions

In rural areas a residential dwelling is almost always at ground level. There is a potential complication in urban areas. For example, if an UWT is to be installed on top of a future high rise residential building then the nearest residential property would likely be the penthouse apartment(s) located immediately beneath the wind turbines, which are not yet constructed.

Given that such apartments would be elevated significantly above ground level, they may be exposed to different levels of background noise. If we assume that background noise does not diminish significantly with height up a building in neutral weather conditions it may be reasonable to use background noise level measurements at ground level to assess the expected noise level in the elevated apartments.

However, the wind profile and the background noise level at different wind speeds may potentially be significantly different for elevated apartments in comparison to measurements made at ground level. Elevated apartments will generally be exposed to higher wind speeds and therefore also higher levels of wind induced noise from the building surfaces and the general environment. This considerably increases the level of uncertainty associated with an assessment.

Applicable standards for the assessment of urban wind turbines

The author understands that there are no applicable standards or guidance documents for the assessment of noise from urban wind turbines. It is understood that the American Wind Energy Association and the International Electrotechnical Commission (IEC) are developing future guidance documents (Renewable Energy Research Laboratory 2006).

ALTERNATIVE ASSESSMENT CRITERIA

General noise guidance documents typically require assessment of noise emissions to be carried out in neutral weather conditions where wind speed is 5m/s or less. This limits their applicability to wind turbines which inherently change their noise emissions with wind speed. However, some examples of general guidance document for noise control that are used in the state of Victoria are noted below for comparative purposes.

SEPP N-1

State Environment Protection Policy (Control of Noise from Commerce, Industry, and Trade) No. N-1 (SEPP N-1) is the Victorian environmental noise policy relating to central building services plant such as cooling towers, chillers and central exhaust fans. The intent of the policy is to protect residential amenity and it requires that plant noise emission complies with the noise limits of SEPP N-1.

Noise limits from SEPP N-1 are set based on land use in the area and existing background noise levels. Noise emission from a premises/noise source is measured at the nearest affected residential properties and corrections may apply for such characteristics as noise duration, intermittency, tonality and impulsiveness.

SEPP N-1 separates the day into three different time periods: day; evening, and; night. Noise limits are determined for each of the nominated time periods, of which the night-time noise limit is the most stringent.

SEPP N-1 stipulates that the night time base noise limit shall not be less than 35dBA.

Residential noise emission

The Environment Protection (Residential Noise) Regulation 1997 is the legislation regarding residential noise emission in the State of Victoria. Statutory Rule No.120/1997 in this regulation sets out provisions for control of noise from domestic appliances including motorized equipment, electric power equipment, domestic air-conditioning plant, swimming pool pumps and musical equipment, whether amplified or not.

The regulation does not prescribe noise limits for the equipment, but it does prescribe allowable hours of operation and thereby prohibits the use of equipment during night time hours. However, Section 4 of EPA Information Bulletin TG 302/92 Noise Control Guidelines considers that if noise from night-time usage were inaudible, then the intent of the regulations would be achieved.

The TG302/92 guidelines are used by local authorities and municipal councils to assess noise issues. The guidelines provide different conditions for different times of the day.

For day and evening operation, where noise from any fixed domestic plant occurs beyond the residential property boundary, the broadband intrusive noise resulting from its use shall not exceed the background noise level by more than 5dBA when measured at the property boundary.

For night time operation, the noise from fixed domestic plant must not be audible within a habitable room of any other residence (regardless of whether any door or window giving access to the room is open) during prohibited hours. The following hours apply to air-conditioners, swimming pool and spa pumps and ducted heating systems.

- Monday to Friday: 2200-0700hrs
- Weekends and Public Holidays: 2200-0900hrs.

The rule demonstrates that inaudibility of wind turbine noise emission within a residential dwelling is likely to minimise the level of complaints from affected residents. Also, it suggests that restricting the operation of noisy equipment during night time hours is a method that can help to minimise noise complaints.

AS2107-2000

Australian Standard AS2107-2000 *Acoustics - Recommended design sound levels and reverberation times for building interiors* provides guidance on suitable internal noise levels within dwellings rather than assessing noise levels externally. Table 1 shows an example of recommended internal noise levels stated in AS2107 for “houses and apartments near major roads.”

Table 1 AS2107 recommended internal noise levels

Area	Recommended internal noise level	
	Satisfactory	Maximum
Living areas	35	45
Sleeping areas	30	40
Work/utility areas	35	45
Apartment common areas	45	50

Source: (AS2107 2000)

AS2107 applies to ambient noise and so considers all noise sources. In practice ambient noise levels in urban areas are often controlled by traffic noise and noise from building services. If noise from UWT's was a component of the ambient noise environment it would need to be less than the AS2107 limits in order to account for the other sources contributing to the ambient noise.

For example, in bedrooms during night time hours, wind turbine noise would need to be designed to around 20-25dBA. Allowing for a 10-15dB sound reduction through open windows this is broadly equivalent to the 35dBA base night-time noise limit described in SEPP N-1.

Sleep disturbance criteria

When intrusive noise reaches certain levels largely independent of background noise, there is a potential for disturbance of sleep and possibly awakening if activities occur during the night period 2200-0700hrs (10:00pm-7:00am). The New South Wales Environment Protection Authority (NEW EPA) publication *Environmental criteria for road traffic noise* reviews a broad range of research into the relationship between noise exposure and sleep quality, concluding:

- Maximum internal noise levels below 50-55dBA are unlikely to cause awakening reactions
- One or two noise events per night, with maximum internal noise levels of 65-70dBA, are not likely to affect health and wellbeing significantly.

Based on these NSW EPA findings, a noise level of 60-65dBA outside an open bedroom window would be unlikely to cause awakening reactions. Most of the research on sleep disturbance is based from vehicle traffic.

Arguably, noise emissions from wind turbines should not cause sleep disturbance. Because wind turbines are not an impulsive noise source, they should achieve much lower noise levels outside and inside of residential dwellings than those listed in the above guidance. It is expected that, where noise emissions from a wind turbine satisfy the noise limits in NZS6808, sleep disturbance will be unlikely.

A POSSIBLE CRITERION

Key factors

Key factors which should be addressed in establishing criteria for UWT’s may include the following:

- Inaudibility in dwellings is ideal but may not be practical
- Background noise levels may be affected by changes in wind speed
- Assessment of noise levels may be required both inside and outside of a dwelling
- Tonal noise may be produced by UWT’s

A possible criterion

The following criterion is proposed for UWT’s in the state of Victoria.

Where wind turbine noise is inaudible inside residential dwellings, with windows open or closed as required for ventilation, noise levels are likely to be acceptable. However, given that residential dwellings are arranged more densely in urban areas, achieving inaudibility may not always be possible and some other noise limits may be needed.

In the absence of any specific planning permit criteria, NZS6808 should be adopted as the assessment standard. Specifically, the noise level from a wind turbine generator or wind farm at a residential site should not exceed the background noise level (L_{A95}) by more than 5dBA or a level of 40dBA L_{A95}, whichever is greater when assessed in accordance with NZS6808. Corrections for tonality shall apply as required by NZS6808.

It should be noted that NZS6808 specifies an assessment location outside of the residential dwelling. Where a wind turbine shares common structural elements with a residential dwelling, such as a roof top turbine which is located above apartments, it may be necessary to also assess internal noise levels. For such an assessment we recommend compliance with SEPP N-1 with corrections made as required for indoor noise measurements.

Also, if the selected wind turbine is expected to operate in wind speeds of less than 5m/s, then we recommend that noise emissions should comply with SEPP N-1 criteria for wind speeds of less than 5m/s.

A possible assessment method

NZS6808 requires a minimum of 10 days continuous background noise monitoring at selected affected sites, together with simultaneous wind speed measurements every ten minutes.

For urban sites it is proposed to place a noise monitoring logger at site, for a period of 15-20 days to collect noise level data over both weekday and weekend time periods. A wind speed monitor would also be required to be placed at site so that the correlation of wind speed to background noise may be established.

After the monitoring is complete, a regression analysis may be performed to describe the relationship between the background noise level and the wind speed. Depending on the trends observed in the measured data, different time periods may need to be analysed separately such as the daytime and night time period and the weekday and weekend period.

This information can then be used to assess compliance with NZS6808 derived noise limits at the most affected residential dwellings.

Noise monitoring should be carried out at ground level. If required, it should also be carried out at the location of existing elevated dwellings. In addition, if future elevated dwellings are proposed noise monitoring should be carried out the height and location of these dwellings where possible.

Comments

The above proposed criterion addresses the key factors outlined above. In addition it is noted that, by establishing noise limits based on existing background noise levels will inherently account for the likely increased background noise level in urban areas. This would not be the case were an absolute noise limit used.

A similar approach applies to internal noise limits where it is recommended to use SEPP N-1 to determine compliance. Such as assessment will therefore consider the background noise level in the area, however there will be no correlation with wind speed. The reason why an internal criterion has been proposed in this way is to protect the arguably more valuable internal acoustic amenity in dwelling where people sleep. It is considered that a maximum noise level should not be exceeded inside a dwelling independent of wind speed. This is particularly important where the UWT shares common structure with the dwelling and there is potential for structure borne sound transmission at any operating speed of the UWT.

CASE STUDY

Elephant and Castle

Research has been carried out on an UWT installed on top of a council housing building in central London (Dance and Liviani, 2008). This research indicates that noise emissions from the UWT have not caused any noise complaints. It was found that background noise levels were not correlated with wind speed due to noise emissions from a large road in the area. It was reported that the UWT was audible at times during windy summer weekend days when the traffic noise levels were relatively low and the residents had their windows open.

CONCLUSION

There is a shortage of noise emission criteria which are suitable for small wind turbines in urban areas. This is due in large part to the special considerations required to assess noise from wind turbines such as variation with wind speed. Such issues are addressed by many guidance documents for larger wind turbines however it is considered that these guidance documents are not ideally suited to small wind turbines in urban areas.

Existing noise emissions criteria have been reviewed for applicability to UWT's and a possible future criterion has been proposed. A brief comparison of background noise levels in urban areas and rural areas has been carried out which is consistent with the expectation that background noise levels in the urban environment are generally higher.

FUTURE WORK

Intended future review work includes review of the UWT at CERES in Melbourne which has already undergone pre and post construction acoustic review as a requirement of the planning permit (Alternative Technology Association 2007). A review of the prototype UWT installed at a Hum City Council site (Alternative Technology Association 2007) is also intended.

In addition, numerical analysis of background noise level and wind speed data for urban locations is required so that the implications of the proposed UWT noise level criterion can be better understood.

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