STAGE 3 - SECTION 32

CHAPTER 11

UTILITIES AND ENERGY

APPENDIX 3 - TECH REPORT:

TURBINES PANELS, NOISE GLARE

Christchurch City Council

Christchurch City Council
2 November 2011
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Plan Change 63 - Turbines Panels, Noise Glare 10/11-101

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Prepared for

Christchurch City Council

Prepared by

AECOM New Zealand Limited
Unit H, 1 Brynley Street, Hornby, Christchurch 8042, P O Box 710, Christchurch MC, Christchurch 8140, New Zealand
T +64 3 363 8500 F +64 3 363 8501 www.aecom.com

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Table of Contents

Executive Summary

Plan Change 63 is a review of the Christchurch City Plan and Banks Peninsula District Plan to address the requirements of the National Policy Statements (NPS) for Electricity Transmission, Renewable Energy Generation, and Telecommunications. Decision-makers on resource consent applications must have regard to the provisions of the NPS, and the plans and policies of local government authorities must therefore give effect to the NPS.

This report has been prepared to provide technical advice on wind turbine noise, and glare from solar panels, to assist the Christchurch City Council in developing robust planning provisions that address the requirements of the NPS. A summary of the report is presented below:

Wind Turbine Noise

The existing Christchurch City Plan and Banks Peninsula District Plan do not incorporate any noise provisions relating specifically to wind turbine noise. It is considered that the existing noise provisions of the plans would need to be modified if wind turbine noise is to be addressed in a robust manner.

A review of the district plans of other Councils throughout New Zealand has shown that, where wind turbine noise provisions are included in the plans, the majority of Councils refer to one of the versions of NZS 6808[1] for the measurement and assessment of wind turbine noise. It is considered that the use of NZS 6808 would also be generally acceptable for measurement and assessment of wind turbine noise under the Christchurch City Plan and Banks Peninsula District Plan.

Solar Glare

The existing Christchurch City Plan and Banks Peninsula District Plan incorporate only basic provisions relating to reflective solar glare. A reactive approach is taken by the plans, whereby glare is only specifically considered if it is found to be a problem, and it then becomes an enforcement matter under the provisions of the Resource Management Act 1991 (RMA).

It is considered that improvements could be made to the existing glare provisions to better address reflective solar glare, by providing some basic rules that would trigger a glare assessment of potentially glare generating developments at the planning stage. However, it is also noted that developing a single objective standard that could apply in general is not likely to be possible, due to the range of variables to determine whether reflective solar glare occurs and the level of impact it causes.

A review of the district plans of other Councils throughout New Zealand has shown that, where provisions addressing reflective glare are included in the plans, they are usually either qualitative statements or include prescriptive measures such as a limitation on the reflectivity of building materials, or a requirement to use matt paint finishes.

Some generic solar panel installation scenarios have been considered with respect to their glare potential in Christchurch and Banks Peninsula. From these scenarios, a simple screening process has been developed, that could be used to form the basis of rules determining whether or not a formal reflection study should be required for any given development.

A range of recommendations detailing the overall approach recommended for control of glare from solar energy installations is presented in the body of the report.

[1] NZS 6808:1998 "*Acoustics – Wind Turbine Noise*" or NZS 6808:2010 "*Acoustics – Wind Farm Noise*"

1.0 Introduction

AECOM was commissioned by the Christchurch City Council to provide technical advice on wind turbine noise, and glare from solar panels, for input to proposed Plan Change 63 of the Christchurch City Plan and Bank Peninsula District Plan.

Plan Change 63 is a review of the Christchurch City Plan and Banks Peninsula District Plan to address the requirements of the National Policy Statements (NPS) for Electricity Transmission, Renewable Energy Generation, and Telecommunications. Decision-makers on resource consent applications must have regard to the provisions of the NPS, and the plans and policies of local government authorities must therefore give effect to the NPS.

Of particular relevance to the technical advice provided in this report is the NPS for Renewable Energy Generation 2011, which essentially defines renewable energy sources as solar, biomass, tidal, wave, ocean current, hydro-electric, wind, and geothermal generation.

As The NPS for Renewable Energy Generation is not accompanied by a National Environmental Standard (NES), district plans are required to provide standards and regulations to implement the objectives and policies the NPS contains. This report has been prepared to assist the Christchurch City Council in developing robust planning provisions relating to noise from wind turbines and glare from solar energy installations at both domestic and commercial scale.

The scope of this report is to:

- Review selected common commercial and domestic turbines and their noise emission levels and characteristics;
- Comment on the types of noise emitted and the levels of annoyance each type might result in;
- Review selected common commercial and domestic solar cells and the levels of glare anticipated;
- Comment on the levels of annoyance each type of solar cell might result in;
- Comment on how effective the existing Christchurch City Plan and Banks Peninsula District Plan noise provisions are in addressing these noise and glare issues;
- Provide advice on any controls which might be needed for sensitive areas;
- Provide technical recommendations with respect to planning provisions to control wind turbine noise and glare from solar energy installations.

As part of this work, a review has been undertaken to establish how wind turbine noise and glare are currently addressed in the district plans of other New Zealand local and regional councils.

This report is structured in two main sections. The first section (Section 2.0) addresses wind turbine noise, and the second section (Section 3.0) addresses glare from solar energy installations.

A glossary of the nomenclature used in this report is presented in Appendix A.

2.0 Wind Turbine Noise

2.1 Introduction to Noise

2.1.1 Fundamentals of Sound

Sound is the sensation produced by periodic pressure fluctuations in the air, or another medium, acting on the hearing organs in the ear. These pressure fluctuations, or waves, are effectively compressions and expansions of the molecules in the medium.

The peak value of the pressure is called the amplitude, measured in Pascals (Pa). The time between each pressure peak arriving at the ear, measured in seconds, is called the period, T. Frequency, in Hertz (Hz), is defined as 1/T and represents the number of peaks arriving at the ear per second. Since the instantaneous magnitude of the pressure wave is dependent on the point in the cycle at which it is sampled, the magnitude of a pressure wave is often referred to in terms of the root mean square (rms) value of the overall waveform. These concepts are presented graphically in Figure 1.

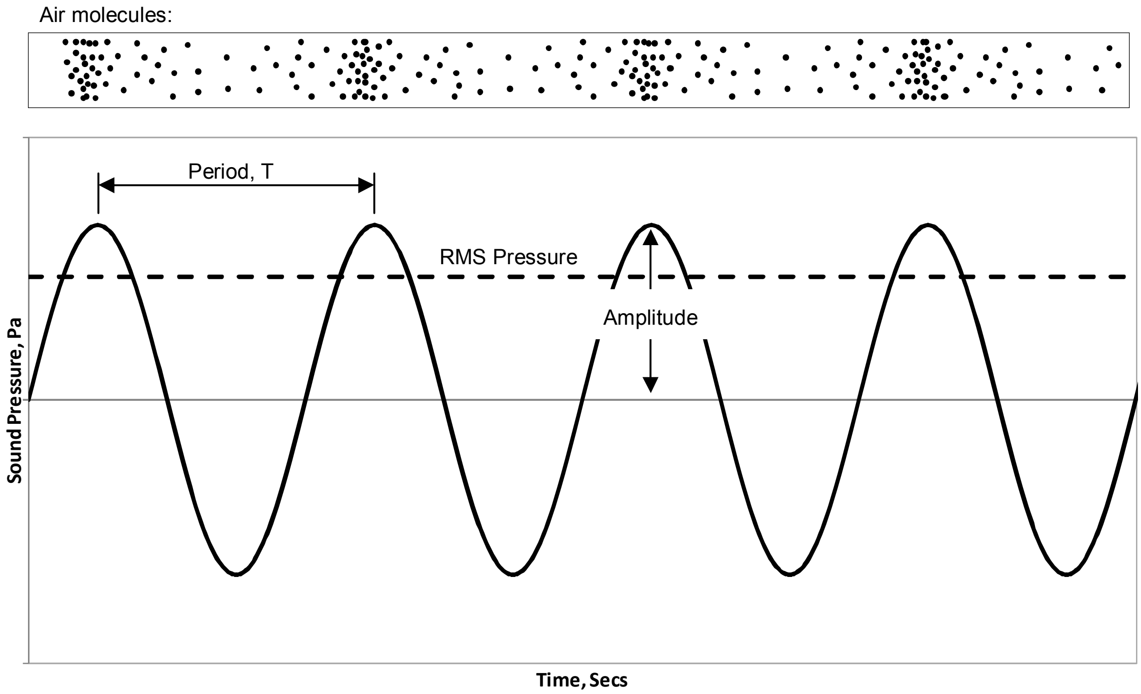


Figure 1 Period, Frequency and Amplitude

When the pressure fluctuations are of sufficient amplitude, and occur at frequencies within the audible hearing range, they are heard as sound. Noise is simply unwanted sound.

The human ear can hear sounds in the frequency range of approximately 20 Hz to 20 kHz. Sound pressures of approximately 20 µPa (rms) are the lower threshold of human hearing. At the upper limit of human hearing, sound pressures of around 20 Pa (rms) are typically the threshold of pain.

2.1.2 Sound Power

Generating the pressure fluctuations we hear as sound requires energy (for example, energy from a vibrating machine casing). The amount of energy that is converted to sound pressure by a sound source, per second, is called the sound power, measured in Watts (W).

Sound power is a property of the source, and unlike sound pressure, which is what we actually hear, it remains the same regardless of how far the listener is from the source, and regardless of the properties of the space in which the sound source is located.

A useful analogy is that of the light bulb. Sound power can be thought of as like the wattage of the bulb, whereas sound pressure is like the level brightness that we actually see. The light from a 100W light bulb installed in a nearby position in a small room will appear much brighter than the light from a 100W light bulb installed in a far away position in a large room, even though the same overall amount of energy is being converted to light.

2.1.3 The Decibel Scale

Due the wide range of sound pressure between the lower and upper thresholds of hearing, it is convenient to use a logarithmic (decibel) scale rather than the linear (pressure) scale. The same applies for sound power.

When describing sound pressure or sound power on a decibel scale, the word 'level' is appended to the end to signify the use of decibels rather than the linear units, i.e. sound pressure level and sound power level.

Sound pressure level and sound power level are defined as follows:

$$L_p = 10\log_{10}\left(\frac{p_{rms}^2}{p_{ref}^2}\right)$$

Equation 1 – Sound Pressure Level

$$L_w = 10\log_{10}\left(\frac{W_{rms}}{W_{ref}}\right)$$

Equation 2 – Sound Power Level

Where:

L_p is sound pressure level in decibels (dB)

p_{rms} is the root mean square sound pressure in Pascals (Pa)

p_{ref} is the reference sound pressure, and is equal to 20 µPa. This value is chosen so that a sound pressure level of 0 dB corresponds to 20 µPa, the lower threshold of human hearing.

L_w is sound power level in decibels (dB)

W is the root mean square sound pressure in Pascals (Pa)

W_{ref} is the reference sound power, and is equal to 1 x 10^{-12} W.

On the decibel scale, a change in sound pressure level of 1 dB corresponds roughly with the smallest change in sound pressure level that can be detected by the human ear in ideal conditions. However, in most practical situations, 3 dB would typically be the smallest change in noise level that is noticeable. To most listeners, an increase or decrease in noise level of 6 dB would be clearly noticeable, and an increase or decrease of 10 dB would typically be perceived as a doubling or halving in loudness respectively. (Note however, an increase of 3 dB actually represents a doubling in sound energy, and an increase of 10 dB corresponds to 10 times the sound energy).

Figure 2 shows examples of the typical sound pressures and sound pressure levels that would be experienced close to various activities.

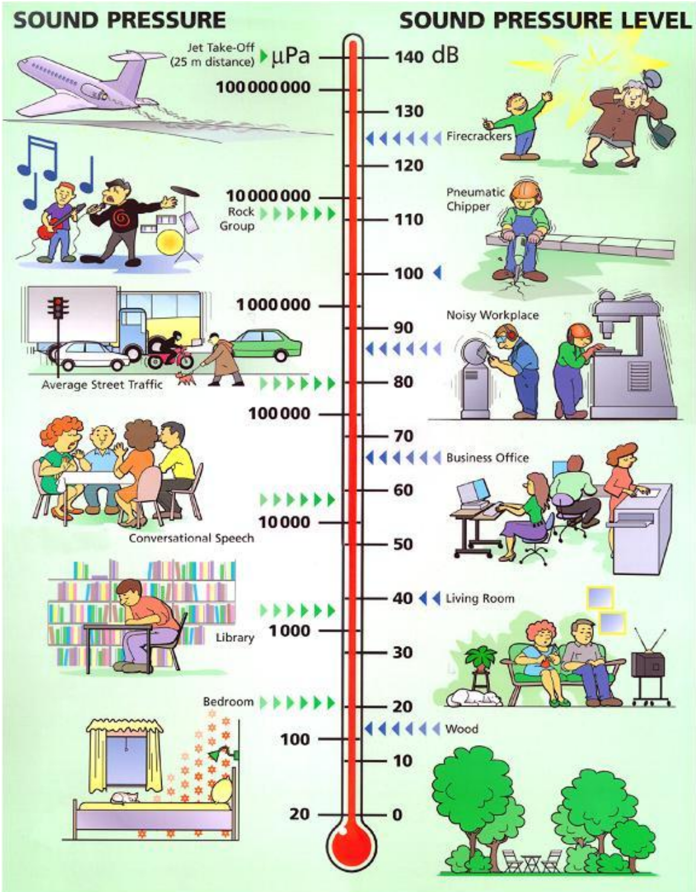


Figure 2 Example Sound Pressure Levels

2.1.4 Human Response to Environmental Noise

The adverse effects of environmental noise on humans can be broadly divided into two categories, as discussed in Table 1:

Table 1 Adverse Effects of Environmental Noise on Humans

Level of Effect	Description
Sensory Overload	This occurs when high levels of sound enter the ear, damaging the hair cells in the organ of Corti, and/or the tympanic membrane. The results may be pain and discomfort, temporary threshold shift (temporary deafness), short term ringing in the ears or long term tinnitus. Permanent hearing damage may occur with prolonged exposure to high levels of sound or with only short exposure to very high levels. It is widely regarded that prolonged exposure to noise levels above 85 dB(A) will result in noise induced hearing loss in the long term.
Psychological Annoyance	This occurs when the level of noise is sufficient, or has such character, so as to cause general annoyance. The short term impacts of this type of noise include effects such as interference with speech communication, difficulty concentrating, irritability, sleep disturbance, and social behavioural changes such as not opening windows or using balconies due to the noise. Whilst this level of noise would normally have any direct physiological impacts on the hearing system itself, prolonged exposure to this type of noise has been associated with various long term health effects, including an increased risk of cardiovascular disease, increase risk of mental disorder, and reduced cognitive ability.

The exact level of noise that will cause psychological annoyance will vary from person to person and will be dependent on the type and characteristics of the sound. In particular, the frequency of the sound plays a significant role in how it is perceived.

In subjective terms, frequency corresponds with pitch. A higher frequency sound has a higher pitch and vice versa. The human ear is more sensitive to some frequencies of sound than others. Typically, humans have low sensitivity to low frequency sounds, and good sensitivity at mid frequencies of 500 Hz to 2 kHz, which corresponds with the dominant frequencies of human speech. As sound pressure levels increase, the response curve of the ear flattens, meaning the frequency of the sound is less important in determining how loud it sounds.

Loudness is measured in a unit called 'phons'. One phon is defined as the loudness of one decibel sound pressure level at 1000 Hz. At other frequencies, a loudness of one phon may correspond to more or less than one decibel, depending on the sensitivity of the human ear to the particular frequency under consideration.

Figure 3 presents equal loudness contours for the human ear, which illustrates the above information. For example, from Figure 3, a loudness of 40 phons corresponds to a sound pressure level of 40 dB at 1000 Hz, but to achieve the same loudness of 40 phons at 100 Hz requires a sound pressure level of over 50 dB.

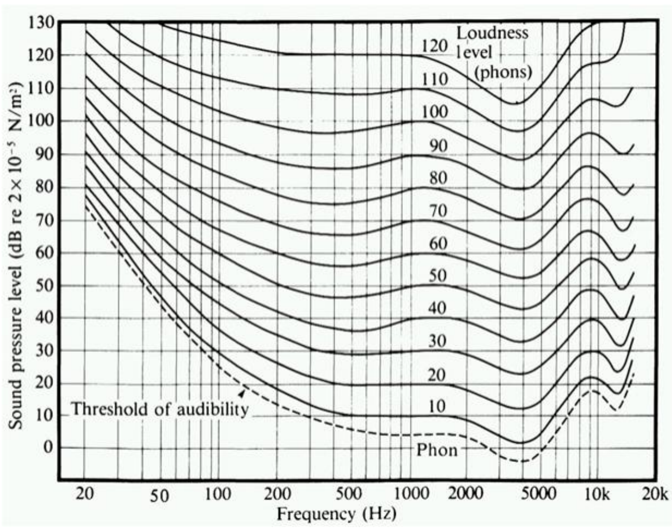


Figure 3 Equal Loudness Contours

Because of the human ear's varying sensitivity with frequency, a frequency weighting called 'A'-weighting is often used in practice to adjust the measured sound pressure level to better reflect the loudness response of the human ear to different frequencies. The shape of the A-weighting curve is shown in Figure 4.

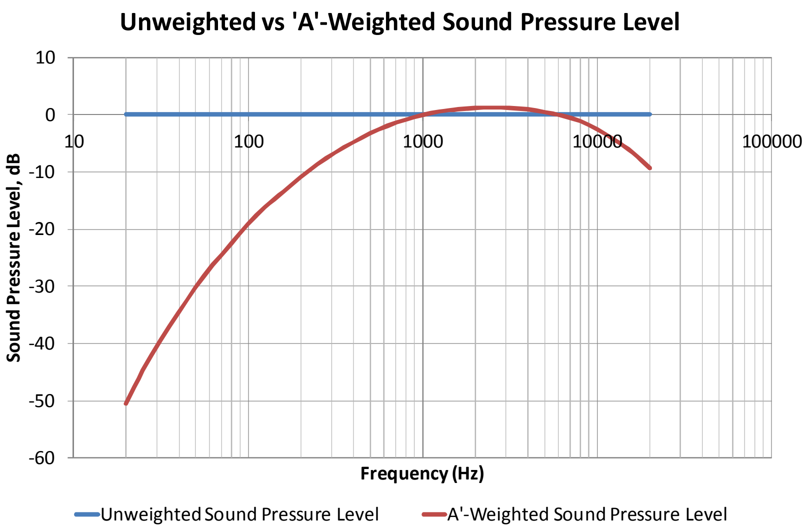


Figure 4 A-Weighting Curve

In addition to the frequency content of a given sound, special audible characteristics, such as tones (prominent sound at a single frequency or within a narrow range of frequencies) and certain temporal characteristics, can change the way a sound is perceived, often making it more audible or subjectively more annoying. On the other hand, background sound can sometimes act to mask the sound or noise under consideration reducing its perceived impact.

2.2 Common Wind Turbine Configurations

Wind turbines come in two basic design configurations - horizontal axis and vertical axis. For horizontal axis wind turbines, the rotor may be upwind or downwind of the tower depending on the design.

Horizontal axis turbines with an upwind rotor are the most common. Vertical axis turbines are typically seen mainly in smaller applications, and building rooftop installations.

Examples of horizontal and vertical axis wind turbines are shown in Figure 5 below.

Figure 5 Left: Example of a Horizontal Axis Wind Turbine (Vestas V90 2MW)
Right: Example of a Vertical Axis Wind Turbine (Quiet Revolution QR5)

2.3 Sources of Wind Turbine Noise

Wind turbine noise can originate from a number of sources associated with the wind turbine.

For commercial scale wind turbines, aerodynamic noise from the rotating blades is usually the dominant source of noise. However, other mechanical components such as the transmission, generator, cooling fans, radiators and oil pumps can also contribute significantly to the overall Sound Power Level of the wind turbine. The relative contribution from mechanical noise is often greater for smaller wind turbines.

Mechanical noise from components in the nacelle can be transmitted to the environment either through direct airborne transmission, for example through a ventilation grille, or through structureborne transmission, where vibration from a component is transmitted through the structure to another component or surface which in turn vibrates to generate noise.

Figure 6 shows the relative Sound Power Level contributions for an example wind turbine.

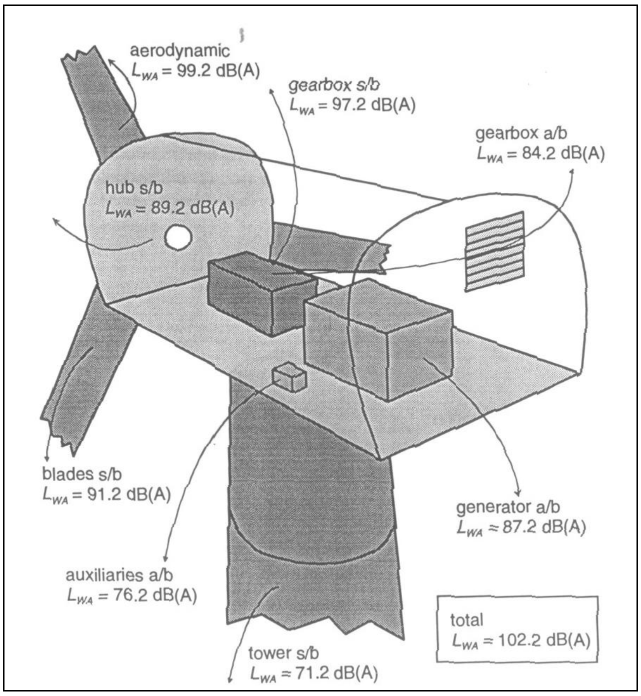


Figure 6 Sound Power Level Contributions for Example Wind Turbine (Note: s/b = structureborne, a/b = airborne) [Source: Wagner S., et al., *Wind Turbine Noise*: Springer, 1996.]

Some wind turbines, particularly smaller ones, use lattice towers and/or guyed towers to support the nacelle. Wind-induced noise can result from guy ropes or structural members in lattice towers, and although not usually a significant source of noise, it can be often be tonal in character, which makes it more likely to cause annoyance.

2.4 Factors Influencing Wind Turbine Noise Impacts

The sound power level generated by any particular wind turbine is highly dependent on its configuration and design. The noise levels resulting at a receptor location due to a wind turbine installation are dependent on both the sound power level of the wind turbine, and environmental factors such as the degree of screening provided by terrain and other structures, and the distance from the turbine to the receptor location. There are also psychological parameters which may play a role in the perceived noise impacts from turbines. Table 2 presents a summary of various factors which can affect the noise impacts from wind turbines.

Table 2 Factors Influencing Wind Turbine Noise Impacts

Influence Type	Factor	Notes	Degree of Influence on Noise Impacts
Sound Power Level / Source Position	Axis orientation	Horizontal axis wind turbines are generally more aerodynamically efficient at converting energy from the wind into power than vertical axis wind turbines. As such, horizontal axis wind turbines often generate slightly less aerodynamic noise than vertical axis wind turbines, for a given power rating. However, vertical axis wind turbines often have an advantage in terms of mechanical noise. With a vertical axis wind turbine the main mechanical equipment, such as the gearbox, generator, oil pumps, and cooling auxiliaries, can be located at ground level at the base of the turbine. This is not usually possible for horizontal axis wind turbines, which normally require all of the mechanical equipment to be located in the nacelle at hub height. The advantage of locating the mechanical equipment at ground level is that noise from the mechanical equipment is more likely to be screened from receptors by intervening terrain, buildings, or other structures.	Low
Sound Power Level	Rotor configuration	Horizontal axis turbines with an upwind rotor are typically quieter than those with a downwind rotor. Wind turbines with a downwind rotor tend to be noisier and impulsive in character due to interaction of the blades with the wake from the tower. This is typically perceived as a thumping sound each time a blade passes the tower.	Med
Sound Power Level	Rotor diameter and power output	Sound Power Levels typically increase with increasing rotor diameter and power output. Larger rotors have more blade surface passing through the air from which aerodynamic noise can be generated. Furthermore, the level of aerodynamic noise from an aerofoil increases exponentially with the velocity of the flow passing over it. For a given number of revolutions per minute, the larger diameter rotor will have a higher blade tip speed and higher airflow velocities along some of its blade length.	High
Sound Power Level	Number of blades	Most wind turbines have two or three blades; however, some small wind turbines have as few as one blade (e.g. Powerhouse Thinair102) or as many as 10 blades (e.g. Honeywell WT6500). Two bladed wind turbines typically need to operate at higher rpm than three bladed wind turbines to achieve the same power output, or require a larger rotor. Since aerodynamic noise increases exponentially with blade speed, for equivalent power outputs, two bladed turbines are often noisier than three bladed wind turbines.	Med

Influence Type	Factor	Notes	Degree of Influence on Noise Impacts
Sound Power Level	Rotating speed	Wind turbines can be designed so that the rotating speed varies with the wind speed, or so that a constant speed is maintained at all times. Small domestic turbines may have rotational speeds as high as 400 rpm, while larger commercial turbines typically operate in the range of 10 to 20 rpm. Aerodynamic noise increases exponentially with blade speed, and blade speed increases with increasing rpm. However, blade speed also decreases with decreasing rotor diameter, so the aerodynamic noise from a small turbine operating at high rpm would not necessarily be any greater than the aerodynamic noise from a large wind turbine operating at low rpm.	Med
Sound Power Level	Blade design	Aerofoil shape and blade tip shape have a significant influence on the level of aerodynamic noise generated. Modifying features such as stall strips, vortex generators, and serrated trailing edges can also influence the noise generated by the blades. For large wind turbines, the blade design is usually optimised to suit a specific wind speed range, taking into account both the efficiency of energy conversion, and the level of aerodynamic noise.	High
Sound Power Level	Nacelle design	The design of the nacelle can affect the amount of mechanical noise emitted from the turbine. The location of cooling vents and radiators, the sound insulation provided by the nacelle, and the degree of other acoustic treatment to the components in the nacelle all influence this.	Med
Sound Power Level	Generator type	The size and type of generator used may affect the levels of mechanical noise produced.	Med
Sound Power Level	Transmission type	Most large wind turbines use a gearbox to step up the slow rotational speed of the rotor shaft to the higher rotational speed required by the generator. The noise levels from the gearbox can vary significantly depending on the design of the gearbox, and in some cases the gearbox can be a source of tonal noise. Many small wind turbines, and some large turbines, such as those produced by Enercon, use direct drive systems. Direct drive systems are typically quieter as they eliminate the gearbox as a source of mechanical noise.	Med

Influence Type	Factor	Notes	Degree of Influence on Noise Impacts
Sound Power Level	Cut-in wind speed	The wind speed at which the turbine starts turning and/or generating power can have an influence on the noise impacts at the receptor locations. If the wind turbine is able to operate at very low wind speeds when there is very little wind-induced background noise at the receptor location, it may be more audible than in the case of a wind turbine that does not begin operating until higher wind speeds where wind-induced background noise would mask the noise from the wind turbine to a greater degree. It should however be noted that many larger wind turbines emit some noise even when not generating, due to the continuous operation of some equipment such as oil pumps and hydraulic power units.	Site dependent
Sound Power Level	Tower Type	Guy ropes or structural members in lattice towers can generate wind-induce tonal noise in certain wind conditions. Freestanding monopole and tubular towers have less potential for wind-induced noise generation. However, if there is inadequate vibration isolation of rotating machinery in the nacelle, monopole or tubular towers have the potential to radiate vibration transmitted to the tower as sound.	Low
Sound Power Level	Power Regulation Method	For pitch regulated wind turbines, the level of aerodynamic noise typically varies with the pitch angle of the blade. Commercial scale pitch regulated wind turbines often have a number of pitch control modes allowing different pitch vs wind speed mappings, which can be selected to reduce the aerodynamic noise from the blades if required (generally at the expense of generating less power). Stall regulated wind turbines operating near to the upper cut-out wind speed may generate increased levels of broadband aerodynamic noise as the blades begin to stall.	Med
Sound Power Level	Design quality	Manufacturers of commercial scale wind turbines typically expend significant design effort to minimise Sound Power Levels. However, for smaller domestic scale wind turbines, the level of design effort expended on noise reduction is highly variable. As such, some domestic scale wind turbines generate almost as much noise as some larger commercial scale turbines.	High

Influence Type	Factor	Notes	Degree of Influence on Noise Impacts
Environmental	Hub height	Wind turbines with higher hub heights are to be less likely to be screened from receptor locations by intervening terrain and structures. As such, where undulating terrain or structures are present between the wind turbine and the receptor locations, the extent of noise effects may be greater for a wind turbine with a higher hub height than one with a lower hub height. Noise may also carry further in the case of a higher hub height, due to less absorption of the wind turbine noise by the ground. However, these noise increasing effects may be offset slightly in some instances by the fact that a higher hub height may place the turbine further from the receptor, and the airflow at the higher height may be less turbulent, reducing the aerodynamic noise generated by the turbine.	Site Dependent
Environmental	Wind conditions at turbine	Turbulent conditions at the site of the wind turbine can increase aerodynamic noise levels from the turbine by several decibels. Increased levels of turbulence can result from the turbine being in the wake of other structures, such as buildings, meteorological masts, trees, or other wind turbines. Wind turbines typically begin generating power at wind speeds in the range of 3 to 5 m/s, and the Sound Power Level of the turbine normally increases with increasing wind speed and power generation, up to the speed where the rated power output is achieved (typically around wind speeds of 12 to 16 m/s). However, the noise impacts from wind turbines are often most significant at moderate wind speeds around the range of 6 to 10 m/s. At these wind speeds wind turbines are typically generating close to maximum noise, but the winds may not necessarily be strong enough to generate a significant level of wind-induced background noise at surrounding receptor locations. At wind speeds above 10 m/s, it is often the case that the wind-induced background noise level at any significant distance from the turbine is greater than the noise level due to the wind turbine, resulting in the wind turbine noise being masked at typical receptor locations.	Med

Influence Type	Factor	Notes	Degree of Influence on Noise Impacts
Environmental	Wind conditions and background noise levels at receptor	Background noise at a receptor will help to mask noise from the wind turbine. Receptors with low levels of background noise may therefore experience a greater noise impact than receptors with higher background noise levels. Background noise levels typically increase with increasing wind speed, as a result of wind induced noise from trees and other vegetation. This usually provides increased masking at higher wind speeds and partially offsets the impact of the increase in noise emission from the turbine as wind speeds increase. However, in some situations wind turbines are located at positions in the vicinity of particularly sheltered receptors (e.g. receptors in a valley, with wind turbines at the top of the hills). In these instances, it may be the case that wind speeds at the wind turbine position are significantly higher than those at the receptor position. Where this occurs, the winds at the wind turbine position may allow the turbine to operate at or close to maximum noise level, while there is relatively little wind and background noise masking at the receptor locations. This situation would result in increased audibility of the wind turbine noise at the receptor location.	High
Environmental	Terrain	The terrain between the wind turbine and the receptor location can have a significant influence on the level of noise received and degree of perceived noise impact. Terrain can act both to screen the receptor location from noise from the turbine, and/or to shelter the receptor location from the wind. The former would result in lower turbine noise levels at the receptor, potentially reducing its noise impact, while the latter would result in lower background noise levels at the receptor during times when the turbine is operating, increasing the audibility of the turbine and its potential noise impact.	High
Environmental	Ground type	Sound propagates more readily over hard ground such as asphalt or concrete, than over soft ground such as grass or heavily vegetated areas. However, the differences are typically not significant over short distances.	Med
Environmental	Prevailing wind direction	Wind can enhance or reduce the propagation of sound. Receptors upwind of the wind turbine will generally be less affected by noise from the wind turbine, while wind may increase the noise levels received at receptors directly downwind of the turbine. Receptors downwind of the turbine with respect to the prevailing wind direction may therefore be more impacted by wind turbine noise than those upwind of the turbine with respect to the prevailing wind direction.	Med

Influence Type	Factor	Notes	Degree of Influence on Noise Impacts
Environmental	Receptor Distance	Sound pressure levels decay logarithmically with distance. Receptors closer to the wind turbine will experience higher levels of noise than receptors further away (in the absence of any other effects such as shielding from terrain).	High
Psycho-Acoustic	Tonality	Tonality can increase the perceived loudness of a particular sound, and its level of annoyance. Tonality is often observed in noise emissions from small wind turbines; however this is becoming less common as small wind turbines designers are increasingly being forced to reduce tonality to satisfy the noise criteria specified in planning regulations. Larger wind turbines sometimes exhibit tonal characteristics, but it is much less common than in small wind turbines. Significant design effort is usually applied to avoid tonality in large wind turbines because many planning regulations require a+5 dB penalty to be added to the noise level where tonality is present in the noise spectrum. This is turn has a major effect on the minimum distance at which the noise criteria can be achieved, and may affect the viability of a commercial venture as it may mean that fewer turbines can be installed compared with the case of a turbine that does not exhibit tonality.	High
Psycho-Acoustic	Amplitude Modulation	The regular variance of noise level with time is termed amplitude modulation. The occurrence of amplitude modulation can increase the level of annoyance perceived from a wind turbine or wind farm. Amplitude modulation is present to some degree for all horizontal axis wind turbines due to the blades passing the tower, and is generally more pronounced for turbines with downwind rotors. The effects of amplitude modulation may be more significant where multiple wind turbines are installed. In these cases, periods may occur when the modulating noise levels of several turbines become synchronised, combining to give rise to particularly pronounced amplitude modulation.	High
Psycho-Acoustic	Impulsivity	Impulsive sound is transient sound with a short duration peak level, typically less than 100 milliseconds. Impulsiveness can make the sound from a wind turbine more annoying. The sound from horizontal axis wind turbines with downwind rotors often exhibits impulsiveness, due to interaction of the wake from the tower with the blades as they pass the tower.	High

Influence Type	Factor	Notes	Degree of Influence on Noise Impacts
Psycho-Acoustic	Low-frequency noise	Sound with a frequency of less than 200 Hz is typically termed low frequency sound. Low frequency noise tends to carry further than high frequency noise, as the sound absorption provided by the air and ground is less than for higher frequencies. Horizontal axis wind turbines with downwind rotors often exhibit strong low frequency noise components associated with the thumping noise that can be created by the blades interacting with the wake from the tower. Some research suggests that strong low frequency components in noise from a wind turbine may increase the level of annoyance generated. Claims have also been made about adverse health effects related to low frequency noise exposure, but there is little actual evidence to support such claims.	Low / Med
Psycho-Acoustic	Visibility	Visibility of the wind turbine from the receptor location may increase the psychological perception of noise at the receptor location.	Med
Psycho-Acoustic	General perception of development	Objectors to the wind turbine development may be significantly less tolerant of noise from the wind turbines than those who are supportive of it, and may find even low levels of noise annoying.	Med
Other	Noise from ancillary equipment	Noise from equipment associated with the wind turbine can also have an influence on the degree of annoyance caused. Substations, and in particular, transformers, typically generate a tonal hum with a fundamental frequency equal to twice the supply frequency (i.e. for New Zealand's 50 Hz power supply, the fundamental frequency of noise is 100 Hz). As both low frequency and tonal noise from substations has significant potential to cause annoyance if located too close to any noise sensitive receptors. Wind turbines which are designed for use in remote areas where there is no other power supply sometimes incorporate backup diesel generators to supply power to the turbine control systems, and/or the consumer, during periods when the wind is insufficient to drive the turbine. In other instances, wind turbines may be used for pumping or milling rather than electricity generation, and there may be additional mechanical noise associated with these systems.	Low / Med
Other	Noise from construction and maintenance	Construction and maintenance activities associated with the wind turbine may have an influence on the overall noise impacts of the wind turbine development.	Low / Med

2.5 Noise Levels of Example Wind Turbines

To provide guidance on the general levels of noise that can be expected from wind turbines of various sizes, a review of the sound power levels of a range of typical wind turbines has been undertaken.

Figure 7 presents a chart of the relationship between wind turbine sound power level and rotor diameter for the reviewed range of wind turbines at 8m/s. A wind speed of 8 m/s is the mid-point in the wind speed measurement range recommended by IEC 61400-11 "*Wind Turbine Generator Systems – Part 11: Acoustic Noise Measurement Techniques*", and would be a commonly occurring wind speed at many turbine sites. Figure 8 presents a chart of the relationship between wind turbine sound power level and rotor diameter with the turbine operating at 95% of rated power. Under NZS 6808:2010 "*Acoustics – Wind Farm Noise*", the calculations based on the sound power levels at 95% rated power are used to determine the extent of the area applicable to the assessment.

Noting that since rated power typically increases with increasing rotor diameter, similar trends are observed if the sound power levels are graphed in relation to rated power, rather than swept rotor area, as shown in Figure 9 and Figure 10.

Details of the wind turbines from which Figure 7 to Figure 10 are drawn are tabulated in Appendix B, along with the sound power levels of the turbines at other wind speeds.

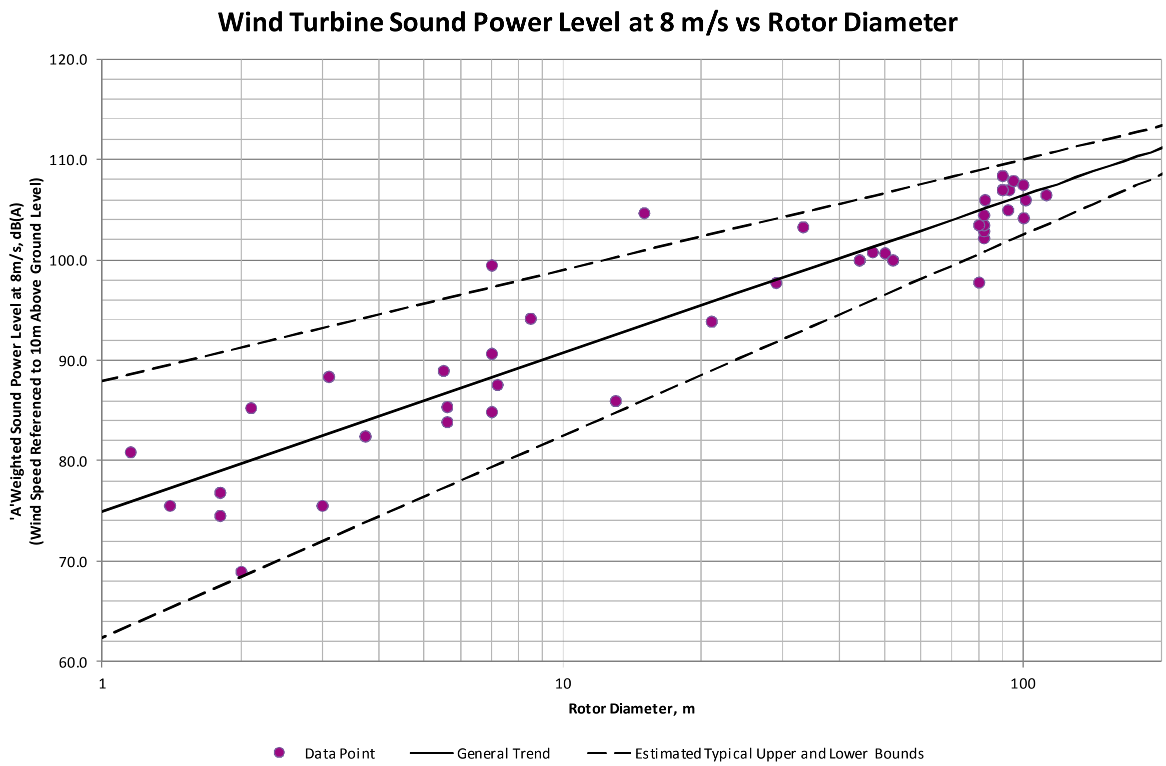


Figure 7 Sound Power Level vs Rotor Diameter for Selected Various Wind Turbines Operating at a Wind Speed of 8 m/s at 10m above Ground Level

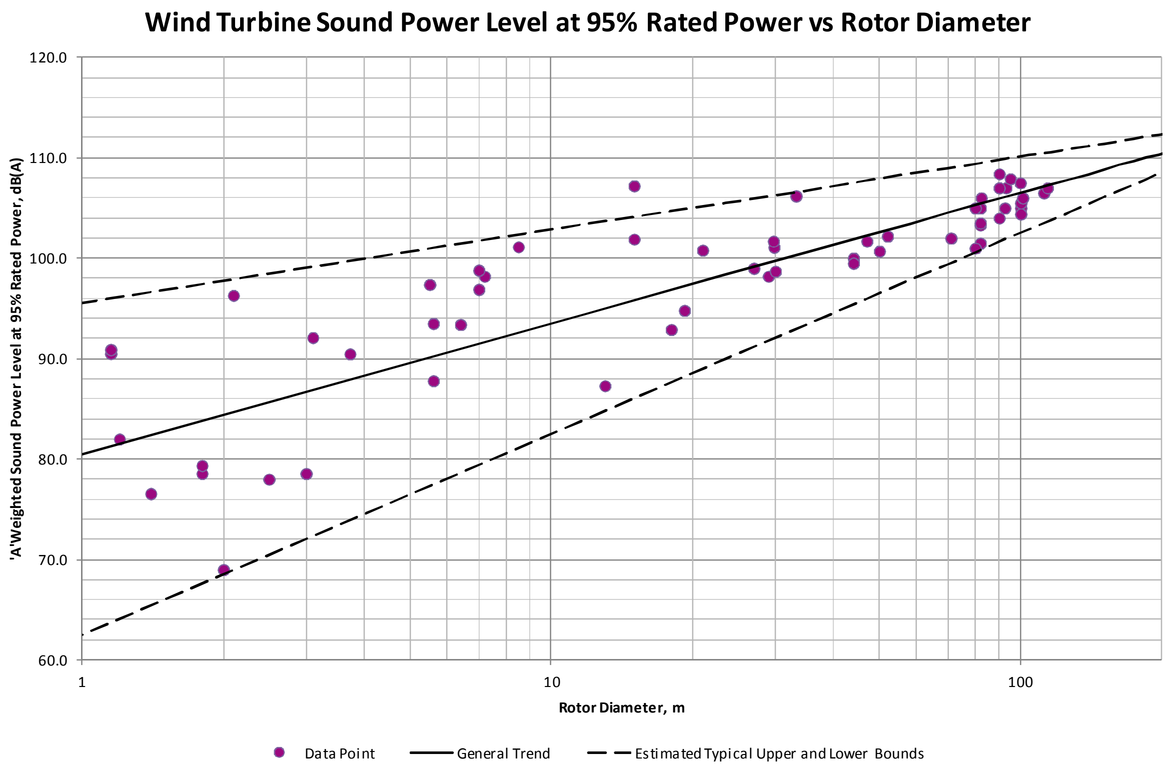


Figure 8 **Sound Power Level vs Rotor Diameter for Selected Various Wind Turbines Operating at their Rated Power**

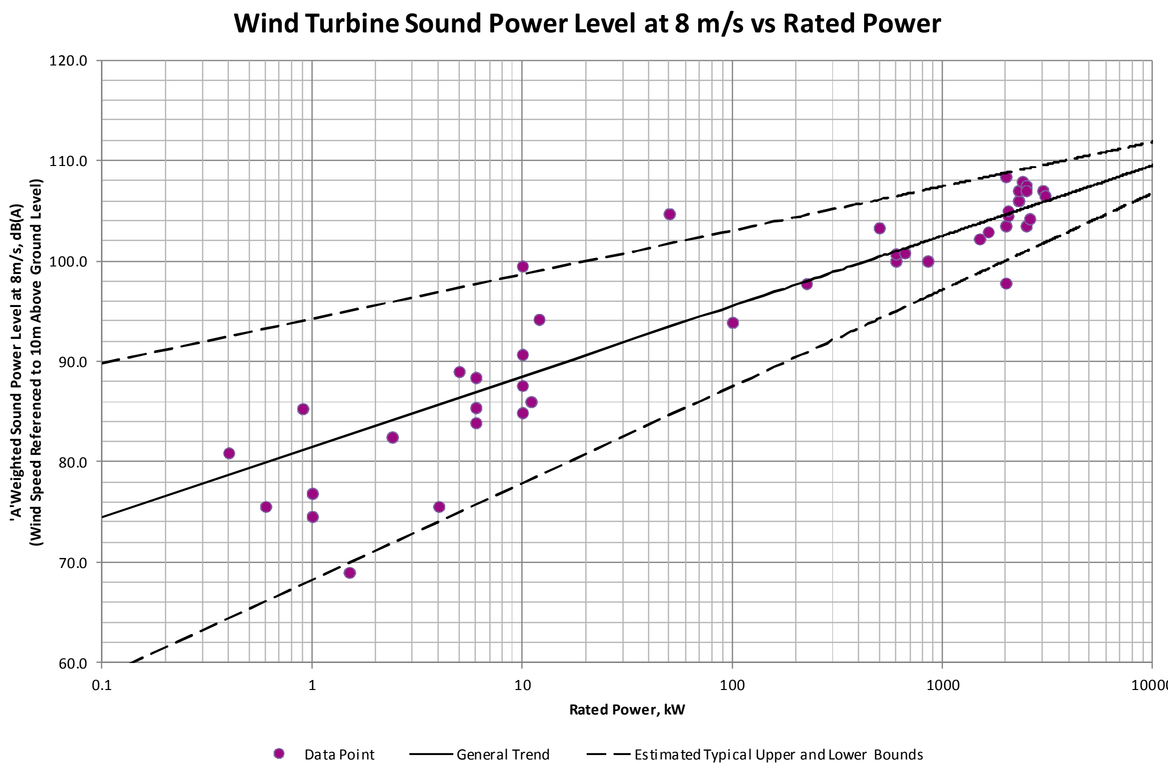


Figure 9 **Sound Power Level vs Rated Power for Selected Various Wind Turbines Operating at a Wind Speed of 8 m/s at 10m above Ground Level**

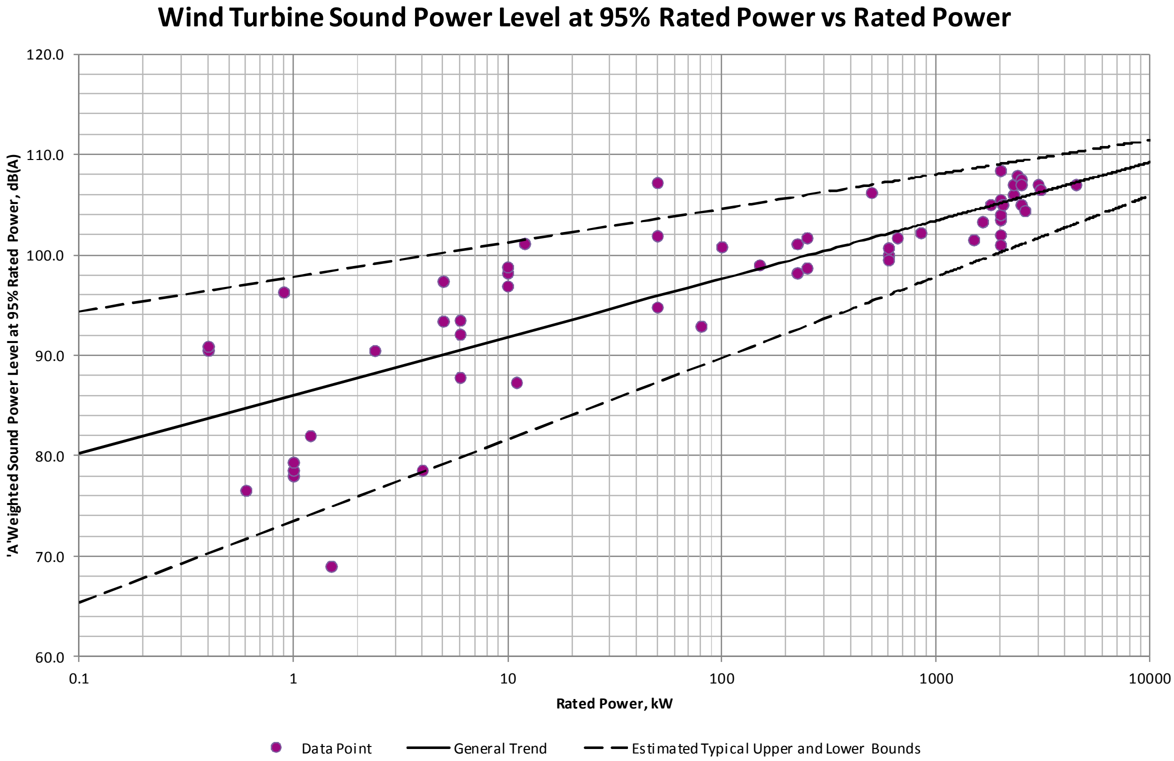


Figure 10 **Sound Power Level vs Rated Power for Selected Various Wind Turbines Operating at their Rated Power**

2.6 Review of Existing Planning Provisions

2.6.1 Christchurch City Plan

The operative Christchurch City Plan does not make any specific provision for wind turbine noise. The current noise provisions of the plan prescribe for noise measured in accordance with NZS 6801:1991 "*Acoustics – Measurement of Sound*" and assessed in accordance with NZS 6802:1991 "*Acoustics – Assessment of Environmental Sound*".

It is a requirement of NZS 6801:1991 that measurements of sound be undertaken during periods of wind speed less than 5m/s, and therefore, without modification NZS 6801:1991 is unsuitable in the case of wind turbine noise measurements, where wind speeds of 5m/s are likely to be at the lower end of the range of interest.

Further to this, NZS 6802:1991 specifically excludes wind turbine noise from its scope. As such, the ordinary noise limits of the Christchurch City Plan cannot be strictly applied to wind turbine noise.

In addition to the above, it is appropriate for wind turbines to have wind speed dependent noise limits, since noise from wind turbines typically increases with increasing wind speed, and so does the level of masking background noise.

Although there are no limits in the Christchurch City Plan that are strictly applicable to wind turbine noise, the provisions of Section 16 of the Resource Management Act 1991 (RMA) must still be satisfied. In the absence of guidance from the Plan on what constitutes "reasonable" noise, a developer could potentially use any recognised wind turbine noise criteria and method of assessment to demonstrate reasonable noise under Section 16 of the RMA.

New Zealand Standard 6808:1998 "*Acoustics – Wind Turbine Noise*", and more recently the 2010 version, has typically been used as the basis of assessment in other New Zealand districts where resource consent applications for wind energy facilities have been lodged and the District Plan has not had specific provisions to address wind turbine noise. Despite this, the use of a different assessment standard would not be precluded if it could be justified. As such, planning decisions on matters of wind turbine noise may be open to potential inconsistency under the current provisions of the Christchurch City Plan.

2.6.2 Banks Peninsula District Plan

Similarly to the Christchurch City Plan, the Banks Peninsula District Plan does not make any specific provision for wind turbine noise, and the ordinary noise limits of the Plan make reference to NZS 6801:1991 and NZS 6802:1991. As such, the situation for the Banks Peninsula District Plan with respect to wind turbine noise is the same as discussed above for the Christchurch City Plan.

2.6.3 Wind Turbine Noise Provisions of Other NZ and Australian Authorities

Currently, only a few District Councils in New Zealand make specific provision for assessment of wind turbine noise under their operative District Plans; however some District Councils are in the process of preparing updated District Plans, which do include provisions for wind turbine noise. A summary of the wind turbine noise provisions included in the operative and proposed District Plans of other New Zealand Councils is presented in Table 3. (Note: In preparing this table the district plans of all other New Zealand Councils have been reviewed. Where a Council is not listed, it means that no specific provisions in relation to wind turbine noise were found in the district plan for that Council).

Table 3 Summary of Wind Turbine Noise Provisions in New Zealand District Plans, as of July 2011

District Council	Summary of Wind Turbine Noise Provision
Ashburton District	The operative district plan does not contain any specific provisions for wind turbine noise. However, the proposed District Plan states that wind turbine noise is a permitted activity if it complies with NZS 6808:2010, and is otherwise a restricted discretionary activity.
Carterton District	The Plan states that: "Where NZS 6802:1991 does not include assessment of the type of noise in question, other appropriate Standards may be used as specified in the definition for "Noise Emission Level". The definition for Noise Emission Level given in the Plan refers to NZS6806:1998 for wind turbine noise. Note that the Plan pre-dates the current (2010) version of NZS 6808.
Gisborne District	Refers to DZ 6808:1997 (a draft version of NZS 6808:1998) for measurement methodology but is unclear as to whether the ordinary zone noise limits still apply for wind turbine noise or if the limits prescribed by DZ 6808:1997 are to be used for assessment.
Hastings District	States that noise measurements shall be undertaken in accordance with NZS 6808:1998 but states that compliance is to be assessed in relation to the ordinary L_{A10} zone limits. It is unclear how this would be applied in practice, since the measurement methodology prescribed by NZS 6808:1998 is based on L_{A95} noise levels rather than L_{A10}, and NZS 6808:1998 specifically notes that L_{A10} noise levels are unsuitable for the assessment of noise from wind turbines.
Marlborough District	The noise rules for the 'Rural Zone' and the 'Sounds Residential Zone' state that noise from any generator or wind powered equipment used solely for the generation of electricity shall not exceed 55 dB L_{A10} at all times at the notional boundary of any dwelling. Wind turbine noise limits are not provided for other zone types.
Masteron District	Same as Carterton District.
New Plymouth District	Refers to NZS 6806:1998 for measurement and assessment methodology. Wind turbine noise is a permitted activity if the L_{A95} level from the wind turbine does not exceed the L_{A95} background level + 5dB or 40 dB, whichever is the greater (this is the same as recommended by NZS 6808:1998). Where wind turbine noise does not comply with the limits it is classified as a Restricted Discretionary Activity. Note that the

District Council	Summary of Wind Turbine Noise Provision
	Plan predates the latest version of NZS 6808.
Porirua City	States that: "All sound levels shall be measured in accordance with NZS 6801:1991 Acoustics – "Measurement of Sound". Where NZS 6802:1991 does not include assessment of the type of noise in question, the appropriate New Zealand Standards may be used." This provides for NZS 6808 to be used for assessment of wind turbine noise.
Queenstown Lakes District	There are no specific wind turbine noise provisions in the operative District Plan, however, Proposed District Plan Change 27a "*Updating Noise Measurement and Assessment Standards*" states that the ordinary zone noise limits shall not apply to noise sources that are excluded from the scope of NZS 6802:2008 and refers to NZS 6808:1998 for wind turbine noise. In addition the proposed plan change sets an 85 dB L_{AFmax} limit for "wind machines" – however, it is speculated that the intent of this L_{AFmax} limit is for wind-generating machines used for agricultural purposes to protect crops from frost, rather than wind machines in the context of wind turbines.
South Wairarapa District	Same as Carterton District.
Tararua District	Wind farms treated as discretionary activity (see 2.8.4 Renewable energy generation and wind farms, 5.3.7 Energy Generation Facilities). Section 5.3.7 refers to NZS 6808:1998 for assessment of operational noise, and NZS 6083 for construction, or any subsequent versions of these standards.
Waikato District	Wind turbine noise is a permitted activity if it complies with NZS 6808:1998. Note that the Plan predates the latest version of NZS 6808.
Wellington City	The Wellington City Council District Plan has specific chapters relating to renewable energy (Chapter 25 and 26). Chapter 25 notes that the only renewable energy source addressed by the current provisions is wind energy but that the chapter should be amended as other options such and solar, wave and biomass become more viable. Chapter26 (Rules) focuses on wind energy in rural / open space areas. Chapter 26 provides for wind turbines as a discretionary activity and the normal zone based rules do not apply. Noise is identified as a criterion for consideration, but no particular limits or standards of wind turbine noise assessment are specified. The provisions exclude small scale turbines (<5kW)– referring back to the ordinary zone rules.
Whakatane District	The operative district plan does not contain any specific provisions for wind turbine noise. However, the proposed District Plan states that wind turbine generators with a swept area greater than 80 m^2 shall comply with NZS 6808:2010, and shall otherwise be a discretionary activity. Noise from wind turbine generators with a swept area less than 80 m^2 would need to comply with the ordinary zone noise rules.

In Australia, wind turbine noise has historically been assessed in relation to a number of standards and guidelines, varying from state to state. These include, but are not limited to:

- The South Australian "*Wind Farms Environmental Noise Guidelines*" 2009 (South Australian Environment Protection Authority, 2009);
- The South Australian "*Wind Farms Environmental Noise Guidelines*" 2003 (South Australian Environment Protection Authority, 2003);
- Australian Standard AS 4959:2010 "*Acoustics – Measurement, Prediction, and Assessment of Noise from Wind Turbine Generators*";
- New Zealand Standard NZS 6808:2010 "*Acoustics – Wind Farm Noise*";
- New Zealand Standard NZS 6808:1998 "*Acoustics – Wind Turbine Noise*"; and
- The currently draft "*National Wind Farm Development Guidelines*" (Australian Environment Protection and Heritage Council, 2010).

The paper presented in Appendix C compares the differences between some of the approaches used in Australia, including NZS 6808.

2.7 Issues for Consideration

2.7.1 New Zealand Standard 6808:2010

New Zealand Standard 6808:2010 "*Acoustics –Wind Farm Noise*" (NZS 6808) provides methods for the prediction, measurement and assessment of sound from wind turbines, and is designed to be applied where wind farm development proceeds under rules in a national environmental standard, plan or planning process such as a resource consent application. It is considered that reference to this standard would therefore be appropriate in any wind turbine noise update to the Christchurch City Plan and Banks Peninsula District Plan.

NZS 6808 uses L_{A90} noise levels rather than the L_{A10} and L_{Aeq} noise levels used by the District Plan. L_{A90} noise levels represent the level of noise that is exceeded for 90 percent of the time during a given measurement period. As such, L_{A90} noise levels are better suited to the assessment of wind turbine noise than L_{A10} and L_{Aeq} noise levels because the L_{A90} noise levels are less affected by sporadic short term periods of high background noise induced by wind gusts and periods of higher energy wind. If the L_{Aeq} or L_{A10} noise levels were to be used, the influence of these short term events could potentially dominate the L_{Aeq} or L_{A10} noise level, and the resulting measurements would not represent the sound level due to the wind turbine.

NZS 6808 sets site specific L_{A90} wind turbine noise limits taking into account the fact that background noise levels (and wind turbine noise levels) typically increase with increasing wind speed, meaning higher levels of wind turbine noise are generally acceptable during periods of higher wind.

The general methodology used by NZS 6808 for the setting of noise limits is as follows:

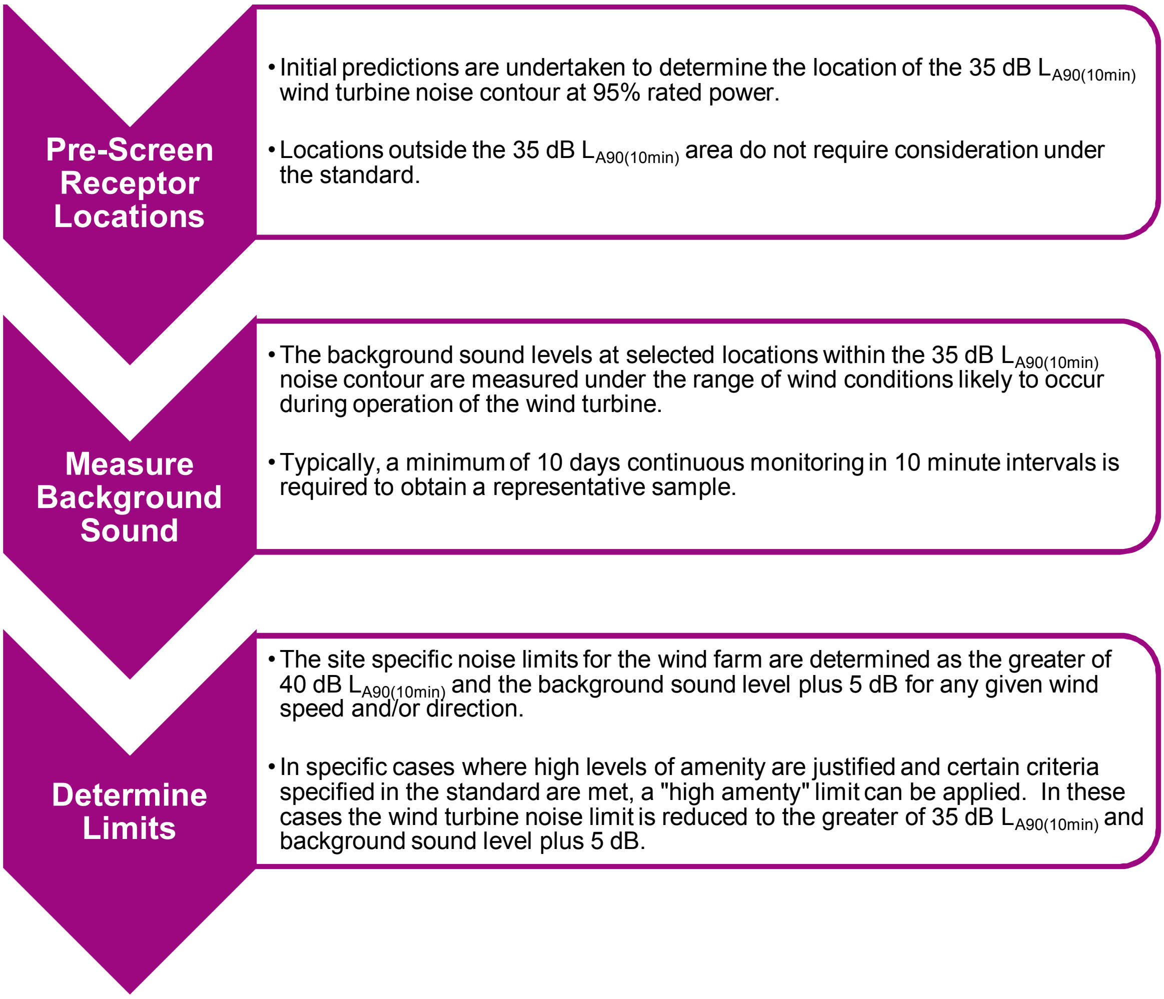


Figure 11 Summary of Method for Determination of Noise Limits Under NZS 6808:2010

The lower limit of 40 dB L_{A90} prescribed by NZS 6808 is the limit that would apply in calm and/or low wind conditions when background noise levels are low. Under the Christchurch City Plan, the time-average noise limits for Group 1 Zones (the most noise-sensitive zones) are 50 dB L_{Aeq} (daytime) and 41 dB L_{Aeq} (night-time). These limits are based on the measurement and assessment being undertaken in calm conditions as required by NZS 6801:1991 and NZS 6802:1991.

Noting that a wind turbine could operate at any time the day, and that the night-time period would therefore be the controlling period in terms of noise, the lower limit prescribed by NZS 6808:2010 would be consistent with the ordinary noise limits prescribed by the Christchurch City Plan for Group 1 Zones.

However, using the above reasoning it would be appropriate to allow an increased lower limit for Group 2 and 3 Zones, where background noise levels would typically be higher. Under the Christchurch City Plan, the time-average ordinary noise limits for Group 2 and 3 Zones are less stringent at 57 dB L_{Aeq} (daytime) and 49 dB L_{Aeq} (night-time). Based on the ordinary noise limits, it is considered that the lower limit for wind turbine noise could appropriately be increased to 50 dB L_{A90} for Group 2 and 3 Zones.

It should be noted that NZS 6808 is intended primarily for commercial scale wind energy developments. The methods of assessment used in the Standard require extensive background noise analysis prior to installation of the wind turbine or wind farm. If assessment of wind turbine noise in accordance with NZS 6808 was to be required by the Plan for all wind turbine installations, the cost of undertaking such an assessment could potentially discourage small scale domestic wind energy installations.

NZS 6808 states that a wind turbine operator may choose not to conduct background noise measurements if a wind farm noise limit of 40 dB $L_{A90(10min)}$ or less is adopted for all wind speeds, and if on/off noise testing is conducted if required. However, this does not remove the need to undertake a predictive analysis, or potential post-installation compliance testing. As such, this might still present a barrier that would discourage small scale domestic developments.

NZS 6808 notes that noise due to small wind turbines is generally covered by the provisions of NZS 6801:2008 "*Acoustics – Measurement of Sound*" and NZS 6802:2008 "*Acoustics – Environmental Noise*", but with special measurement procedures required to take account of the presence of wind. The standard suggests that for wind turbines of up to 15 kW, it would normally be appropriate for the wind turbine noise levels to comply with the ordinary district plan noise limits applicable to mechanical and electrical equipment. Again, this does not necessarily remove the need to undertake a predictive analysis, or potential post-installation compliance testing.

Given the above, an investigation has been undertaken to determine if it would be beneficial to specify a prescriptive standard for control of noise from small wind turbines < 15 kW, rather than a performance based standard, in order to minimise the level of assessment required for small installations and encourage these types of developments to proceed where they are appropriate. Section 2.7.2 discusses this matter further.

2.7.2 Small Wind Turbines

An approach that could be taken in controlling noise from small wind turbines without automatically requiring a predictive assessment would be to specify a buffer zone around residential dwellings and other noise sensitive premises, outside ofwhich wind turbines may be installed without acoustic assessment. (Note that this would not exempt wind turbines installed outside the buffer zone from complying with the noise standards, it would simply act as a screen to prevent any developments that are likely not to comply).

Taking this approach, it would be appropriate for the buffer zone to be sized so that the ordinary noise limits of the Plan are likely to be achieved for most cases.

Over flat ground, with no significant vegetation or structures between the turbine and the receptor, the sound pressure level at a given distance from a turbine can be approximated by the following equation:

$$L_R = L_W - 20\log_{10} R - \alpha R - 8$$

Equation 3 – Sound Pressure Level at Distance (Ref. NZS 6808:1998)

Where

- L_R is the sound pressure level at distance R from the turbine [dB]
- L_W is the sound power level of the turbine [dB]
- R is the distance of the observation point from the turbine [m]
- α is the air absorption coefficient, which is dependent on frequency, air temperature, and humidity. For the purpose of a simple calculation, a reasonable approximation of α for overall A-weighted sound pressure level is α = 0.005 dB/m. [dB/m]

Using Equation 3, the distance (R) at which the turbine sound pressure level would be less than a given value can be calculated.

A review of the typical sound power levels produced by currently available wind turbines with a rated power of less than 15 kW suggests that the sound power levels of such turbines would generally be no greater than 102 dB L_{Aeq} at 95% rated power.

If such a turbine had special audible characteristics, the noise level from the turbine would normally be subject to an adjustment of +5 dB in a practical assessment. Therefore, for the purpose of determining a buffer zone that could generally be used to achieve compliance with the District Plan noise limits for wind turbines with rated power less than 15 kW, a sound power level of 107 dB L_{Aeq} has been used to account for potential special audible characteristics.

From Equation 3, a single wind turbine with a sound power level of 107 dB L_{Aeq} would require the buffer distances presented in Table 4 and Table 5 in order to comply with the existing noise limits of Christchurch City Plan and Banks Peninsula District Plan. The controlling noise limit presented in the tables is the noise limit that the Plans prescribe for the night time period, as the wind turbine could potentially operate during this period and it is the period when the noise limits are the lowest.

Table 4 **Buffer Zones to Achieve Christchurch City Plan Noise Limits for Small Wind Turbine with L_W = 107 dB L_{Aeq}**

Christchurch City Plan				
Zone	Development Standard		Critical Standard	
	Controlling Noise Limits for Zone	Buffer Distance Required	Controlling Noise Limits for Zone	Buffer Distance Required
Group 1 Zones	42 dB L_{A10} 41 dB L_{Aeq} 65 dB L_{AFmax}	572 m	48 dB L_{A10} 49 dB L_{Aeq} 75 dB L_{AFmax}	271 m
Group 2 Zones	n/a	n/a	48 dB L_{A10} 49 dB L_{Aeq} 75 dB L_{AFmax}	271 m
Group 3 Zones	48 dB L_{A10} 49 dB L_{Aeq} 75 dB L_{AFmax}	271 m	n/a	n/a

Table 5 **Buffer Zones to Achieve Banks Peninsula District Plan Noise Limits for Small Wind Turbine with L_W = 107 dB L_{Aeq}**

Banks Peninsula District Plan		
Zone	Controlling Noise Limits for Zone	Buffer Distance Required
Lyttelton Port Zone	n/a	n/a
Industrial Zone for Lyttelton	45 dB L_{A10}	398 m
All other zones	40 dB L_{A10} 70 dB L_{AFmax}	623 m

Note: The buffer distances presented in the tables above are slightly conservative since no allowance for sound absorption by the ground has been included in the calculation. Also, in cases where the wind turbine is to be sited in terrain that is not flat, the buffer distances required could potentially be less than those presented in the tables above, due to screening of the receptors from the wind turbine by intervening terrain.

For wind turbine developments in urban areas, and many rural residential areas, it is likely that the buffer zones above would not be achievable in the majority of cases, due to the typical property densities. There would therefore appear to be little value in specifying buffer zones as an initial screening measure, since a site specific acoustic assessment would be required in the majority of cases anyway.

Further to this, there is significant variability in the range of sound power levels of wind turbines with rated power less than 15 kW. It is likely that this variability would result in many cases where wind turbine developments could be located well within the above buffer zones and still achieve the district plan noise limits.

For example, in the range of <15kW turbines sampled in this report (see Appendix B) the sound power levels at 95% rated power vary from approximately 70 dB(A) to approximately 102 dB(A). A wind turbine with a sound power level of 70 dB(A) and no special audible characteristics would satisfy the noise limits for the Group 1 Zones at a distance of only 11m.

Similarly, future developments in technology could potentially reduce wind turbine noise levels meaning that any buffer zones determined based on current wind turbine noise levels may be larger than needed for quieter turbines in the future.

Additionally, where more than one wind turbine is to be installed, buffer distances calculated based on one wind turbine may not be sufficient, due to the cumulative noise effects of multiple turbines. In these situations, a site specific noise assessment would need to be undertaken to ensure that the impact of wind turbine noise would not be unreasonable.

On the basis of the above, it is considered that it would be best to provide rules that allow for each development to be individually assessed in relation to appropriate noise limits, rather than using a prescriptive approach based on buffer zones.

Where a site specific noise assessment of small wind turbines is undertaken at the planning stage, it is considered that the assessment should be undertaken in accordance with NZS 6808:2010, rather than the ordinary District Plan rules, because the measurement and assessment procedures used in the ordinary District Plan rules do not include procedures to account for the effects of wind. If the ordinary District Plan rules were to be used for the purpose of small wind turbine noise assessment, a special measurement procedure would need to be included in the rules to account for the influence of wind noise on the measurements. It is considered far simpler, and more consistent with other NZ district plans, to use NZS 6808:2010 as the basis of assessment.

2.7.3 Construction and Maintenance Noise

Construction of wind turbine installations typically involves heavy machinery and the use of power tools. Some machinery that would typically be used in the construction wind farm can have sound power levels of 120 dB(A) or more. Certain aspects of the construction work may only be able to be undertaken during calm conditions, and this may correlate with times when the background sound levels at the receptors are lowest and the construction noise would be most audible.

Given the above factors, and the fact that large wind energy developments may take several months to construct, there is potential for unreasonable noise effects to occur during construction of these facilities if construction noise is not adequately managed.

Due to the temporary nature of construction noise and the unique challenges associated with managing construction noise, a separate New Zealand Standard, NZS 6803:1999 "*Acoustics – Construction Noise*" has been developed for the purpose of its measurement and assessment. Construction noise is specifically excluded from the scope of NZS 6802 and NZS 6808.

While it would also be appropriate for NZS 6803:1999 to be applied to noise from occasional major maintenance and repair activities, it is considered that routine maintenance activities should comply with the ordinary noise limits of the District Plan, including noise associated vehicle movements on the wind turbine site.

2.7.4 Substation Noise and Noise from Other Auxiliary Equipment

A range of noise generating auxiliary equipment may be associated with wind energy developments including substations, transformers, switchgear, communications equipment, heating and cooling plant for site buildings, and other electrical and mechanical devices. In some circumstances, wind-induced noise from the guy ropes and lattice structures of meteorological masts can also be significant.

The noise levels generated by substations and other auxiliary equipment can vary considerably, depending on the size and type the equipment. For example, a small transformer may have a sound power level of less than 60 dB L_{Aeq}, meaning that the sound pressure level at 5 m would be less than 40 dB L_{Aeq}. However, a larger transformer may have a Sound Power Level in the range of 85 to 90 dB L_{Aeq}, requiring a distance of over 125 m from the transformer to before the sound pressure drops to the same level of 40 dB L_{Aeq}.

In most situations, noise from substations and other auxiliary equipment would be covered by the provisions of NZS 6801 and NZS 6802, and therefore, it would be generally appropriate for the ordinary noise limits of the District Plan to apply to these sources.

The noise from substations will often be subject to an adjustment (penalty) when assessed in accordance with NZS 6802, to take account of the additional annoyance typically experienced due to its tonal and low frequency character.

2.8 Technical Recommendations for Plan Change 63

The following recommendations are provided for Plan Change 63, with respect to control of wind turbine noise:

1) Noise from wind turbines should be measured and assessed in accordance with NZS 6808:2010 or any subsequent revision.

2) Noise from wind turbines should be a permitted activity where it complies with the limits prescribed by NZS 6808:2010.

3) For Group 2 and 3 Zones, and the Lyttelton Port and Industrial Zones, it is recommended that the lower limit prescribed by NZS 6808:2010 should be relaxed to 50 dB L_{A90}. i.e. the limits for Group 2 and 3 Zones would be the greater of 50 dB L_{A90} or 5 dB(A) above the background level (L_{A90}).

4) Where a noise assessment is conducted in accordance with NZS 6808:2010 (or any subsequent revision) and the noise levels generated by the wind turbine development are determined to exceed the limits prescribed for some or all of the proposed operating conditions, wind turbine noise from the development should be a Discretionary Activity under the Plan.

5) Noise associated with construction, demolition, and major / non-routine maintenance of wind energy facilities should be a Permitted Activity if it complies with the requirements of New Zealand Standard 6803:1999 "*Acoustics – Construction Noise*" and does not exceed the noise limits recommended in Table 2 and Table 3 of the Standard. Otherwise, construction noise should be a Discretionary Activity.

6) Noise from sources associated with wind turbine developments, other than from the wind turbines, including substations, telecommunications equipment, high voltage power lines, regular routine maintenance activities, and vehicles on private roads within the wind farm, should be measured and assessed in accordance with the ordinary district plan noise rules.

3.0 Glare from Solar Energy Installations

3.1 Introduction to Glare

The human eye adapts readily to high and low light situations but the ability of the eye to distinguish forms is related to the contrast ratio of the scene it is observing. This is in turn related to the luminance of the scene and the object within the scene. Luminance is an objective measurement of the amount of light entering the eye [Unit: Candelas per square meter (Cd/m^2)]. Generally, if the average luminance level (the brightness of a scene) increases, the ability of the eye to determine the relative size, luminance and contrast of individual objects improves. This is referred to as visual acuity. However, if the luminance level of light becomes too high for the particular adaptation, the visual acuity reduces. This is referred to a glare. This is most readily experienced by looking directly into the sun on a clear day (high light level adaptation) or looking into a candle at night (low light level adaptation).

Glare can be classified into three broad categories as discussed in Table 6 below.

Table 6 Glare Categories

Glare Type	Description
Sensory Overload (Disability Glare)	This occurs when high levels of luminance enter the eye and the visual system is overloaded with the quantity of light.
Optical Image Degradation (Veiling Glare)	This occurs when light from a bright source scatters across the retina, reducing the contrast of the scene which reduces the visual acuity.
Psychological Annoyance (Discomfort Glare)	Whilst not causing a sudden loss of visual acuity, elements of sensory overload and optical image degradation produce discomfort for the observer. If prolonged, this can eventually lead to perceptual problems in the visual system.

3.1.1 The Human Eye

All of these glare categories are framed in reference to the human eye. This highlights the relationship between the glare source and the observer and is of particular import when undertaking a glare assessment. The eye has evolved to include two types of receptors (cones and rods) which provide a range of ocular rendition. Because of this, the sensitivity of the eye changes over the field of view. Figure 12 below show the eye's view field and sensitivity.

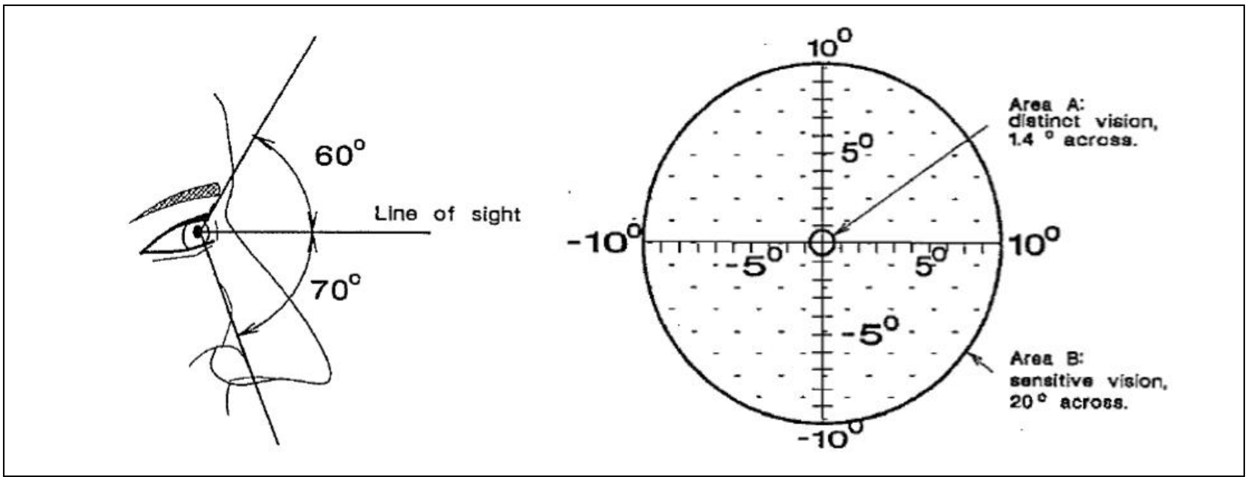


Figure 12 Human Eye's Field of View showing Sensitivity

The distinct area of vision is at the eye's fovea, which is in line with the centre of the eye and extends 0.7° to either side. There is then a greater area of approximately 20° width/height which is sensitive. Glare sources impacting on the sensitive or distinct areas of the view field will cause disability or veiling glare.

3.1.2 Reflective Surfaces

All surfaces are reflective and are measured in terms of their "reflectivity". Reflectance is the amount of light that is not absorbed or transmitted by a particular surface. Reflectance can be measured at any angle from a surface, with the difference between the incident light level and the light level at an angle equivalent to the incident angle describing the "reflectivity" of the surface for that incident angle. When a single reflectance value is given for a particular material it is generally calculated at an incident angle of 90°. This is shown in the Figure below.

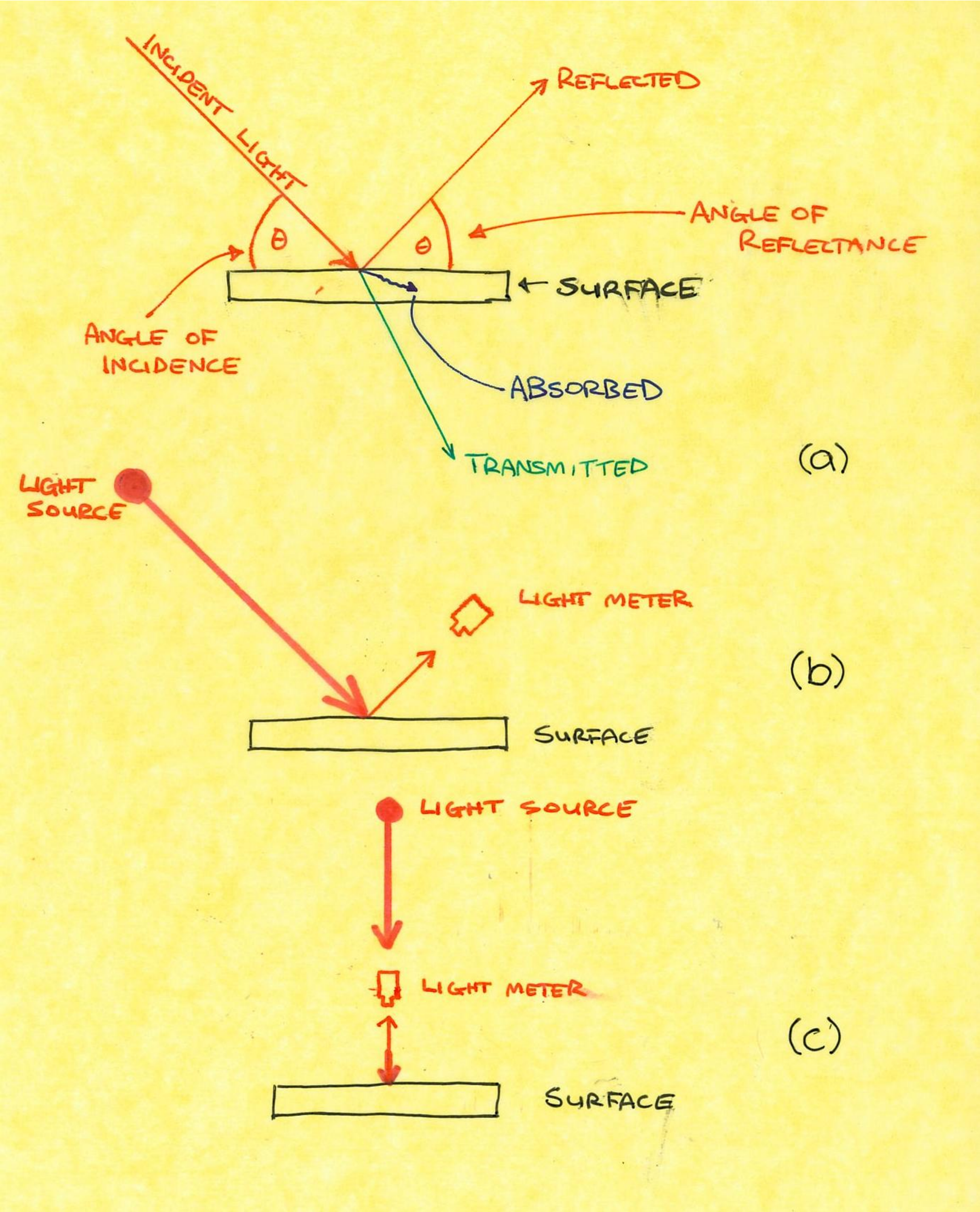


Figure 13 Description of Reflectivity showing Surface Properties (a), The Generalised Measurement Technique (b), and Typical Manufacturer Measurement Technique (c).

Surfaces also reflect light in two different ways. The reflected light can be either diffuse or specular. A diffuse surface (such as a white painted wall) may have a reflectance 85% of the visible light, but not create a glare source as the light is scattered in many directions. A specular surface (such as glass) may have a reflectance of 20% yet create a glare source as all of the reflected light is aligned.

The use of a single reflectance value for a surface does not provide adequate information on how that surface will reflect light in different scenarios. This is especially true for glazed surfaces. The reflectivity of glass is relatively low because it is designed to maximise transmission though the pane. However, at different angles the reflectance values increase.

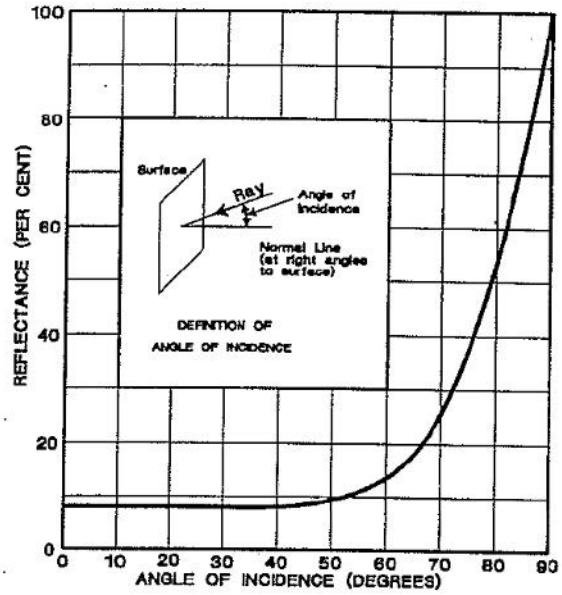


Figure 14 Change in Reflectance with Incidence Angle for Clear Glass.

As shown above in Figure 14, the reflectance increases as the light source becomes parallel with the surface. When the light beam is parallel to the surface (90° in the chart above) the reflectance tends to 100%. Therefore for glazed surfaces, any restriction on reflectance values will only address incidence up to approximately 40° from normal. Whilst this will overcome some of the glare issues related to solar installations, it does not address the more severe glare which occurs at higher angles (relative to normal).

The general location of observers relative to an installed solar panel means that they are more likely to receive light that has been reflected at high incidence angle. In this situation, a low reflectance value does very little to reduce the level of reflected light. This is readily experienced by reflecting the sun's light off the surface of a wrist watch. The intensity of the light is nearly the same as the sun itself even though the reflectance of the watch glass is generally in the order of 10%.

3.1.3 Glare Assessment

Whilst glare is dependent on the quantifiable variables of source intensity, background luminance and observer position, it is also subject to variations in the population. The level of disability or veiling occurring is dependent on the observer's natural visual acuity. Because of this, most studies of glare are limited to geometric exercises to determine if glare will occur and do not discuss the intensity of the glare. One text which provides a quantifiable methodology for glare analysis is David N Hassall's *"Reflectivity: Dealing with Rouge Solar Reflections"*. This methodology is used extensively within New South Wales to assess reflected glare from glass facades. His methodology can also be applied to inclined surfaces and is therefore suitable for assessing solar installations. The process is summarised below.

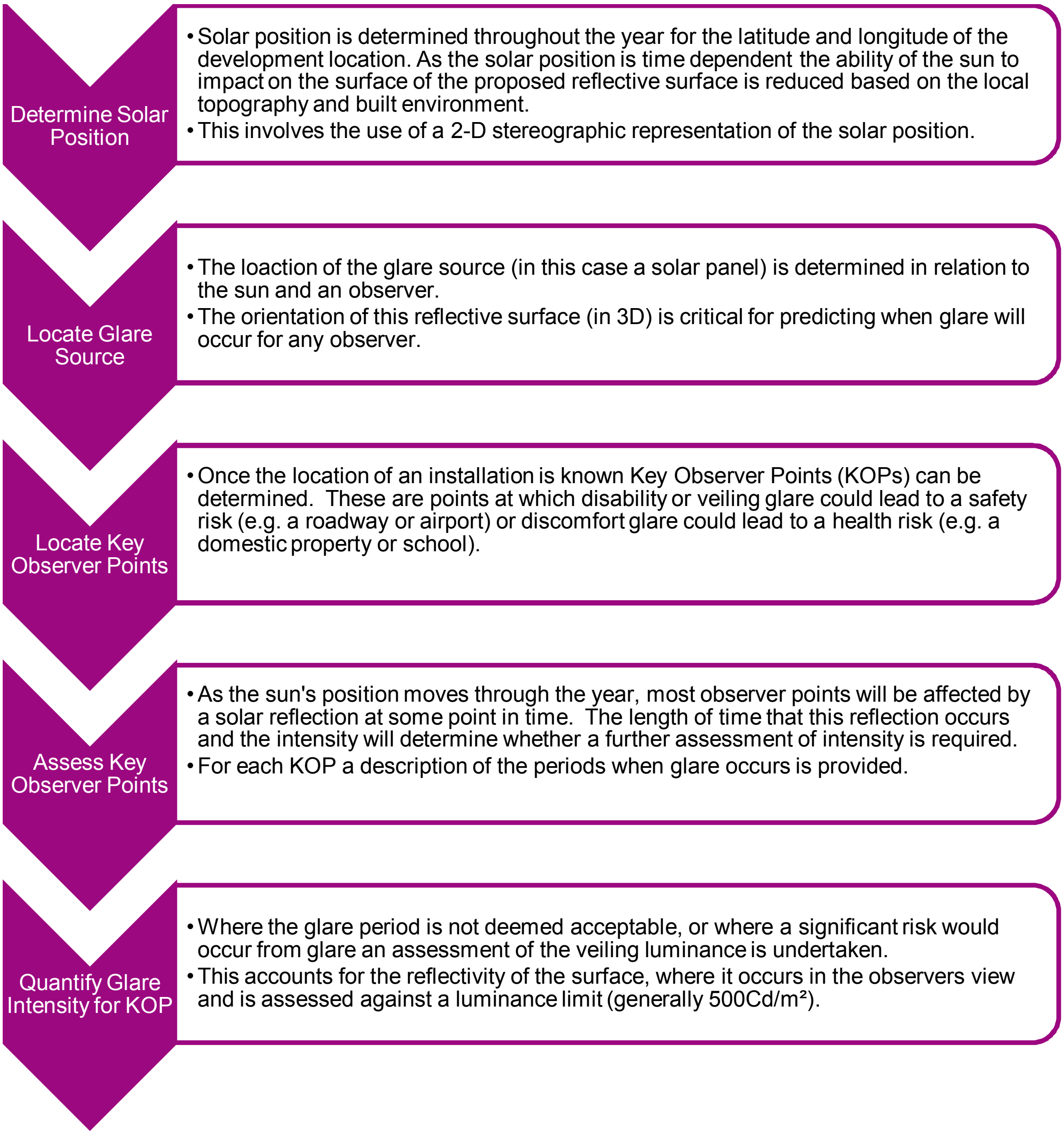


Figure 15 Summary of Glare Assessment Process

This methodology is generally used to assess the impact of glare on drivers from facades and as such has made assumptions about what is acceptable glare. Glare is deemed acceptable if it occurs for a relatively small period of the year and occurs during periods of the day when glare is usually expected, i.e. in the mornings and evenings.

The accepted annual time limits and the intensity level of the glare source will differ depending on the type of observer. Glare studies that concentrate on veiling glare to motorists only will not necessarily provide recommendations to ameliorate discomfort glare. This is most often seen in domestic solar installations that cause glare to neighbouring properties for significant periods throughout the day.

3.2 Types of Solar Energy Installation

The energy of the sun can be harnessed and converted into different types of energy that are of functional use to us. It can be converted to heat energy that can be used for heating spaces (Solar Thermal) or converted to electricity through the use of photovoltaic materials (Solar PV). Several types of solar energy systems are used today. The images below indicate the different types of solar collectors.

Figure 16 Solar System – Clockwise from Top Left: Evacuated Tube Thermal Collector, Flat Plate Thermal Collector, Silicon Photovoltaic Collector, Mirrored Solar Concentrator (Thermal or PV).

Each of the above systems have surfaces which can reflect light and in turn cause glare. Apart from the solar concentrators, all of these systems aim to absorb as much solar energy as possible. This generally results in low reflectance values. However, as the surface of the panels is generally specular, the risk of reflection at high incidence levels can be significant. These systems are commonly used on domestic and commercial installations, with the photovoltaic panels also used throughout the world on an industrial scale.

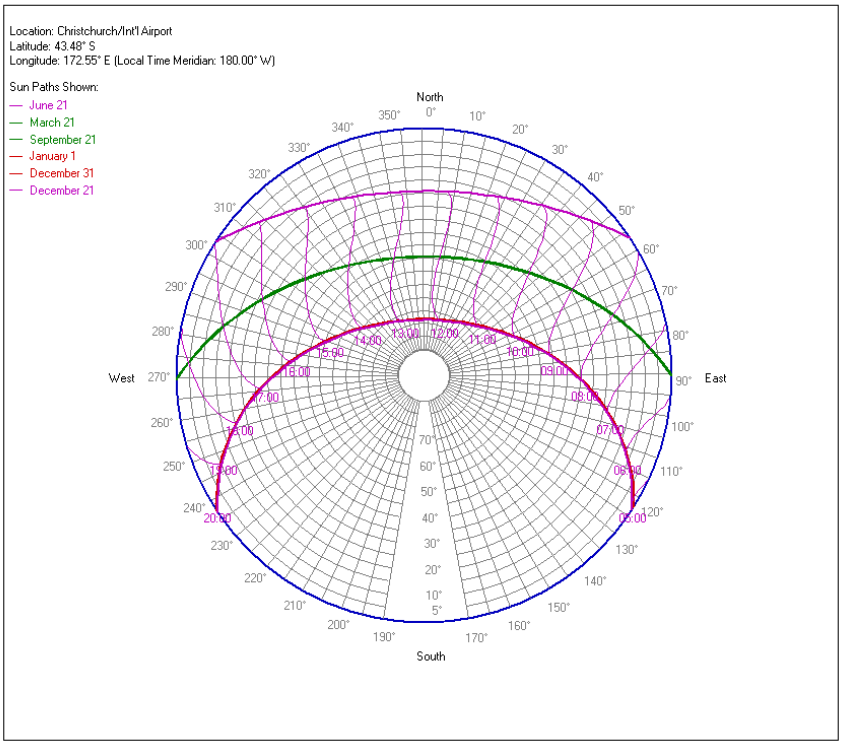
The photovoltaic and flat plate thermal collectors have a single flat surface which makes glare prediction a simple exercise. The evacuated tube thermal collector is an array of curved glass surfaces. This may seem to complicate the glare geometry but they will actually approximate a flat surface of equivalent surface area. All three of these collector types can be referred to as “flat panel collectors”.

In contrast to the flat plate collectors, solar concentrators aim to reflect as much light as possible towards a collection point or line. These systems are curved to target the reflected light towards a collection point (or line) and the glare is much more predictable because of this. This type of system is generally only seen on a large scale, with arrays tracking the sun and providing energy to the electricity grid.

3.3 Factors Influencing Glare from Solar Energy Installations

The following table describes the variables that influence the occurrence and the intensity of glare for a flat panel collector.

Table 7 Factors Influencing Glare Occurrence and Intensity for Flat Panel Collectors

Factors Influencing Glare	Explanation
Observer Position	The position of the observer in relation to the panels is a major factor in influencing the amount of glare that they receive. For a solar installation, there are several observer positions that should be considered: • Observers in adjacent buildings • Motorists • Pedestrians • Other transport The type of observer that is considered in any assessment is generally based on injury risk or long term exposure to nuisance glare. Typically vehicles and residential buildings are assessed. Commercial and industrial buildings are more likely to accept periods of glare as they also receive glare from other building elements such as glass facades.
Time of the Year	The solar position shifts throughout the year and this change in angle will affect the length of time that glare occurs annually. The stereographic diagram below provides a two dimensional description of sun's position in relation to Christchurch.  The green line indicates the sun's path on the equinox with the outer curves describing the solstices. The curved pink lines are constant time lines
Time of the Day	In the morning and afternoons, the sun has a higher incidence angle as the sun is either rising or setting. At these times the incident radiation is close to being parallel to the source of glare and therefore generally more acceptable.

Factors Influencing Glare	Explanation
Location of panel/surface	The collector installation location influences the amount of time that the observer receives glare. Notwithstanding physical obstructions such as other buildings, an inclined plane will generally create less glare when it is installed above the observer.
Direction and angle of panel/surface	Flat panel collectors are usually installed between NE and NW with an angle that is calculated based on the annual yield. An optimised panel in Christchurch would be facing North with a tilt of 30-35°. Although, mounting the panels at an angle of ±20° would still be effective.
Reflectivity of panel /surface	As discussed in the introductory section, the reflective properties of the collector will influence the intensity and direction of the reflected light. Whilst some older solar hot water systems had flat plate collectors that were diffuse, the majority of new systems have a specular surface finish. As glare is predominantly a problem caused by specular surfaces, only systems incorporating a glass surface (or similar) have been discussed.
Size of the panel/surface	The larger the surface the greater the time at which glare can be experienced by a fixed observer. Geometrically the glare source can be described as an area in a two dimensional viewing field. The veiling glare intensity is related to the size of this area and therefore dependent on the size of the reflector.

For tracking solar concentrators, glare should only be a problem if the system is misaligned with the sun. This can occur when collectors are lowered for cleaning or due to other maintenance and safety requirements (e.g. high wind forces).

3.4 Glare Properties of Example Solar Panels and Collectors

The likelihood of a solar panel becoming a glare source is primarily dependent on the geometric arrangement of the sun, the panel and the observer. The intensity is then determined from the panels reflectivity and the size of the glare source relative to the observers view field.

3.4.1 Flat Panel Collectors

Whilst it is relatively simple to source reflectivity values from manufacturers, this information is generally in reference to tests undertaken with a source incidence normal to the panel surface. This provides information on the ability of the panel to absorb solar energy but not on its ability to reduce glare, which will generally have a higher incidence angle.

The following chart (reproduced from Hassall) attempts to provide reflectance values as a function of incidence angle.

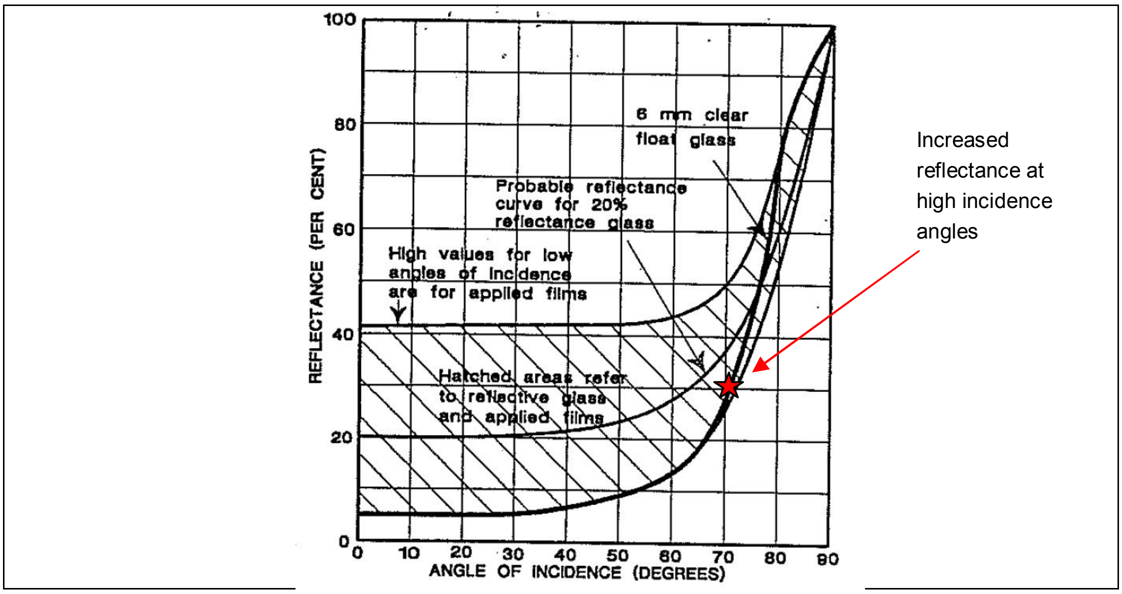


Figure 17 Reflectance as a Function of Incidence Angle for Different Glazing Performances

This shows that even anti-reflective glass (5% reflectance) will have a reflectance of 30% once the angle of incidence reaches 70°. Generally, manufacturer's data does not account for this and therefore any assessment of glare will need to use elevated reflectance values from those quoted by the supplier once the incidence angles increases. As most flat panel collectors use glass as the external skin, the chart above can be used to determine the appropriate reflectance value.

3.4.2 Solar Concentrators

Solar concentrators aim to achieve a reflectance value of 100% and currently values of 95% reflectance are achievable.

3.5 Glare Potential for Typical Installation and Observer Locations

This section identifies a typical solar installation and observer locations for a flat panel collector and discusses the potential for glare to occur and the likelihood of occurrence (based on geometric assessment).

3.5.1 Two Dimensional Analysis

Normally a glare assessment is undertaken in three dimensions. This locates the sun, the observer, any topographical or man-made obstructions and the panel in a 3D space. This type of analysis is time consuming to undertake and needs to be repeated for each potential observer. It is also difficult to develop generalised rules for a 3D space. A two dimensional analysis flattens the observer, panel and sun positions into a single plane, as shown below in Figure 18.

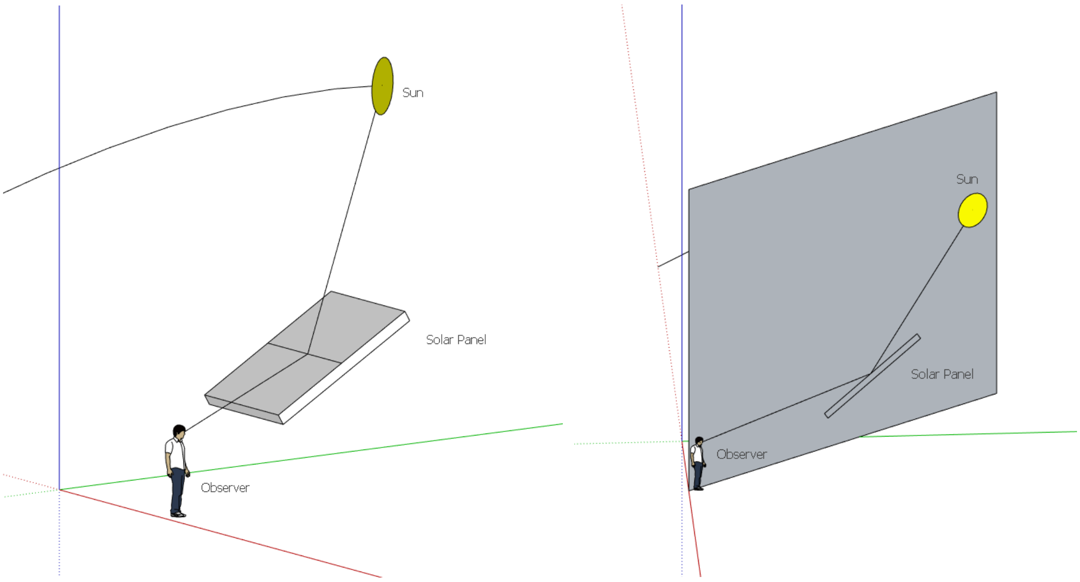


Figure 18 **Description of Flattening a Three Dimensional Analysis into Two Dimensions for a Single Solar Position.**

This 2D representation can be made for any sun position and simplifies the analysis however, it is still not useful for providing simple rules on panel orientation as there are many possible sun positions. If the worst case solar positions are interrogated with this method, then we can formulate rules around these situations that will cover all solar positions. This is provided in the following sections.

3.5.2 Worst Case Two Dimensional Analysis

For this exercise the solar position is described in terms of its Azimuth and Altitude. The Altitude is the angle from the horizon and describes the height of the sun. The Azimuth is the orientation from North and describes the direction of the sun. This is shown below in Figure 19.

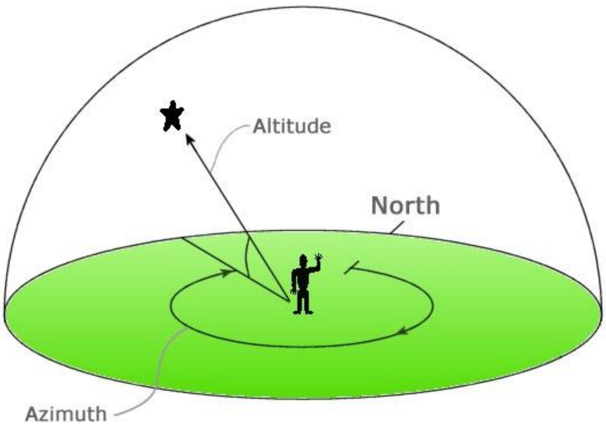


Figure 19 **Solar Position Nomenclature**

Figure 20 below shows a typical ground mounted flat panel collector. It is shown installed at 35°.

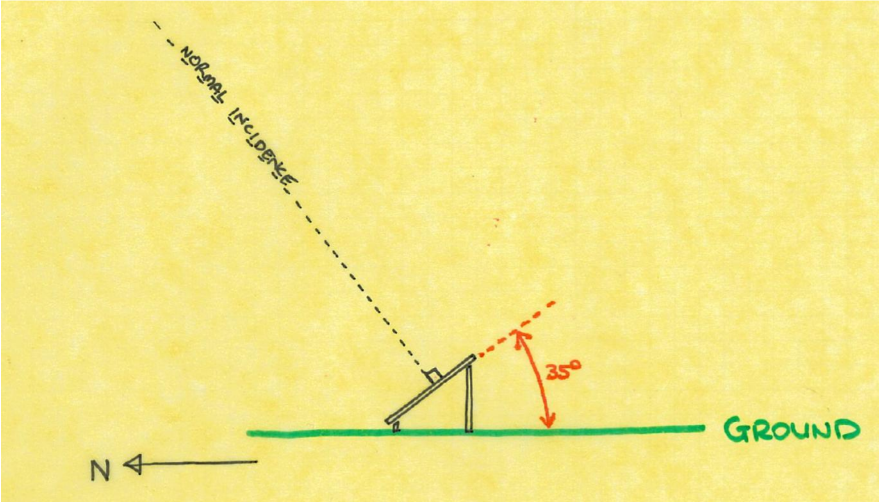


Figure 20 Typical Ground Mounted Flat Panel Collector Installation

As light hits the panel from altitude ∅ it is reflected back at an equivalent incidence angle. This is shown by the blue line in Figure 21 below.

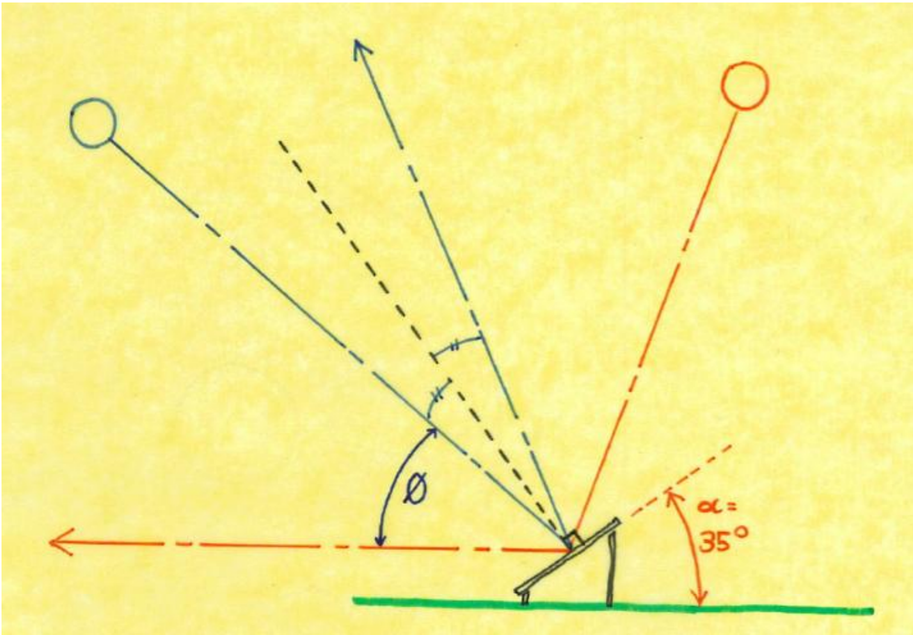


Figure 21 Typical Ground Mounted Installation showing Incident Solar Radiation

By using this relationship we are able to determine the altitude of the sun required for glare to be incident below the horizon (the critical altitude). This is shown in Figure 21 above in red. The expression that describes this is shown below.

$$\emptyset(critical) = 2(90° - \alpha)$$

Equation 4 Critical Sun Altitude

Where ∅ is the critical altitude and (α) is the collector angle.

For the case shown above the critical altitude is 110°. As this sun altitude does not occur in Christchurch there will not be any glare experienced below the horizon for a panel installed at 35°.

Re-arranging Equation 4 allows us to describe the critical panel angle (the angle at which glare impacts on the horizon) for any location based on the altitude of the sun. As the sun's peak altitude is in turn based on the location's latitude, a general expression for the panel angle for any location on the planet can be provided. Equation xx shows the peak altitude as a function of latitude.

$$Peak\ Altitude = 23.5 + (90 - Latitude)$$

Equation 5 Peak Altitude

Combining with Equation xx and re-arranging gives the following Equation for critical panel angle (α).

$$\alpha(critical) = 90° - \frac{[23.5 + (90 - Latitude)]}{2}$$

Equation 6 Critical Panel Angle

As Christchurch's latitude is 43.5° South this gives a critical panel angle of 55°. This means that any panel installed at an angle of 55° or less will not create glare to observers located below the panel. However, in the case of a ground mounted installation, the observer might not be below the panel, meaning there is still a risk of glare. Raising the installation up above the key observer height would remove this risk. Figure 22 below shows some possible key observer points.

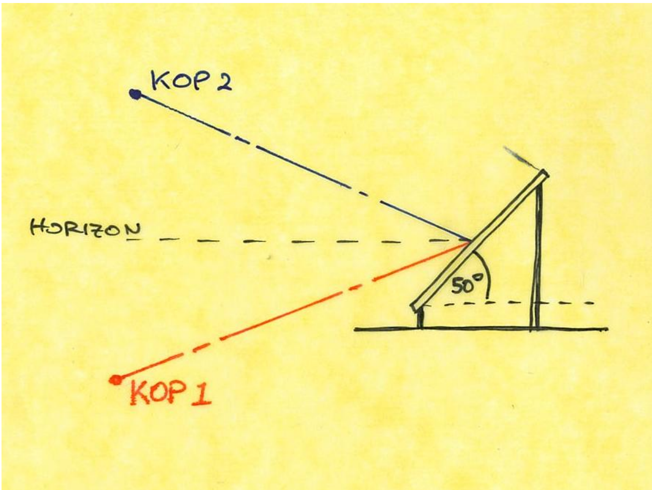


Figure 22 Diagram showing Key Observer Points

KOP 1

This observer will not receive any glare from the solar panel as they are below the installation height and the panel has not exceeded the critical panel angle for Christchurch. This situation would occur for roof mounted panels in an area where all observers are below the panel installation height.

KOP 2

The observer may receive glare from this arrangement. The number of hours that glare would be received can be calculated by undertaking a three-dimensional analysis of the site. This analysis would account for all of the solar positions throughout the year, and the impact of any local shading. If glare occurs for greater than a nominally acceptable period of time the intensity of this glare would also be calculated. This time period and the acceptable level of glare is discussed in Section 3.6.1.

The two dimensional analysis shown above implies that there is a correlation between the angle of the observer to the panel and the panel mounting angle. We have already established that observers below the horizon will not be affected by glare from a panel installed at an angle less than 55°. This idea can now be extended to express a critical panel angle based on an observer who is above the panel. Reducing the panel installation angle below 55° will allow observers to be above the panel and still not receive glare. There is a limit to this reduction in angle though, as observers on the far side of the panel will be affected by low sun angles (worst case scenario of 0° at sunrise and sunset). The impact of low sun on an observer above the installation is shown below in Figure 23.

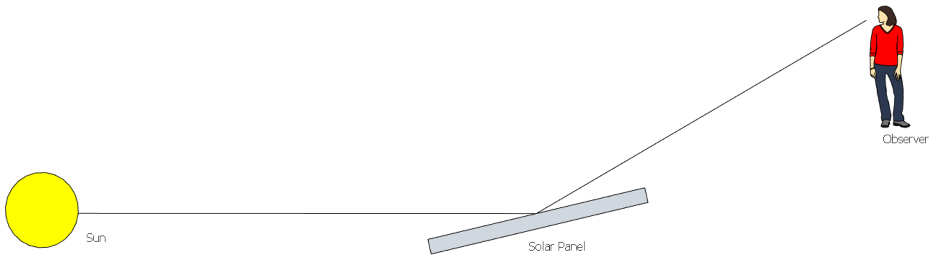


Figure 23 Low Panel Angles will Impact on an Observer above a Panel on Opposite Side from Sun.

We now have two limiting scenarios for an observer, which can be expressed two dimensionally as a function of observer height and distance to give an acceptable range of panel angles. Equation 7below describes the maximum installation angle (based on an observer on the same side of the panel as the sun). Equation 8 describes the minimum installation angle (based on an observer on the opposite side from the sun).

$$\alpha(critical_{max}) = 90° - \beta - \left(\frac{Peak\ Altitude - \beta}{2}\right)$$

Equation 7 Maximum Panel Angle for Specific Observer Location

$$\alpha(critical_{min}) = \left(\frac{\beta}{2}\right)$$

Equation 8 Minimum Panel Angle for Specific Observer Location

In these equations β is the angle of the observer from the installed panel given by Equation 9 below.

$$\beta = \left(tan^{-1}\left(\frac{H}{D}\right)\right)$$

Equation 9 Observer Angle

where H is the height of the observer and D is the horizontal distance from the panel

Graphs for the minimum and maximum installation angle based on observer position relative to the solar panel are provided in Appendix D.

3.5.3 Glare Potential Summary

If the panel is installed above an observer, at a maximum angle of 55°, no glare will be experienced.

If a panel is installed below an observer, glare will not occur if it is installed between the minimum and maximum acceptable angles (which are based on observer locations).

These two requirements would allow most installation locations in Christchurch to be permitted activities as they correlate well with typical installation angles used to maximise the panel efficiency.

The following table describes the installation location, the observers that could potentially be affected and possible mitigation options.

Table 8 Summary of Glare Potential for Typical Flat Panel Collector Geometry

Installation Location	Affected Observers	Glare Reduction Options
Ground Mounted (Flat Land)	All motorists, pedestrians and neighbouring properties could be affected by a ground mounted flat panel collector unless the mounting angle was sufficiently low.	• Provide shielding between the key observers and the installation. • Reduce the installation angle until observers at the boundary are not affected.
Roof Mounted (Flat Land)	Observers above the installation will be affected. This may include multi-storey buildings, low flying aircraft and observers looking down on the installation.	• Shielding between the key observers and the installation.
Roof or Ground Mounted (North facing slope)	Observers up slope from the installation will be affected if the slope angle is greater than the installation angle.	• Increase the installation angle (to a maximum of 55°) • Provide shielding between the installation and the observer.
Roof or Ground Mounted (South facing slope)	Observers above the installation are likely to be affected.	• Shielding between the key observers and the installation.

If a solar panel cannot be installed at an angle sufficient to remove the potential for glare from neighbours and roadways an assessment on the intensity of the glare source and the length of occurrence is required. The following section discusses the process for determining glare levels and duration, and makes recommendations on permitted activities.

As discussed previously, glare from solar concentrators is only likely if there is a misalignment between the sun's position and the tracking angle. If this occurs, the glare risk is significant due to the high reflectivity of the installation. Observers that are located between the concentrator installation and the sun could be affected and the glare intensity would be very high for those located close to the installation. It is recommended that these type of installations undertake a reflectivity risk assessment.

3.6 Quantifying Glare

If the risk of glare cannot be removed by locating and orientating the installation appropriately, the glare should be quantified and assessed against a set of limitations. As the amount of light required to cause disability glare is relative to the background illumination level it is difficult to assess against a single value. An upper limit of 500 Cd/m^2 has been nominated by Hassell, but a much lower illumination could cause glare on a darker day. As the intensity of the glare source is difficult to quantify sensibly it is generally assessed by determining the length of time that the glare occurs for a particular observer, the location of the glare source in the observers field of vision and their ability to ameliorate the glare source (e.g. turn their head or draw a blind).

3.6.1 Period of Glare

For a moving observer (in a vehicle) the period that glare occurs will generally be short as the sun, panel, observer relationship is constantly changing. For a stationary observer, the period that glare occurs is based on the amount of time within the year that the sun, panel and observer are aligned in such a manner. This can only be determined via a three dimensional glare assessment, which will identify the orientation of the observer and the panel relative to the sun for the entire year, taking into account obstructions and topography.

3.6.2 Field of Vision

As discussed previously, the field of vision consists of a sensitive area (approx. 20° wide) and a distinct area (approx. 1.4° wide). If glare can occur to an observer it should be assessed to see whether it would fall into the observers distinct or sensitive vision field. If glare falls into the distinct area of vision this will cause temporary blindness and it will take time for normal vision to be restored. This is usually in the order of a few seconds, although other impairments, such as alcohol, will increase this recovery time. Glare is most likely to occur for observers who are looking slightly up from the horizon, such as in vehicles travelling up a hill. Particular attention should be taken with installations at the top end of inclined roads.

3.6.3 Distance from Observer

As the distance between the observer and the glare source increases, the ability to remove the glare source from their field of sensitive or distinct vision increases. A typical domestic installation of 10m² (3.2m x 3.2m) will completely fill the sensitive area of the eye up to a distance of 9m. This would take a 20° rotation of the head to remove the glare source from the observer's sensitive vision, which is unacceptable for a motorist. If we propose a maximum head turn angle of 2.5% for a motorist then the separation between a 10m² glare source and the observer needs to be 75m. This separation distance is based on the glare source being directly in front of the observer. If it is to one side of the sensitive area of the eye it can be closer.

For a stationary observer, nuisance glare would occur if it was within the field of view at all. However, they are more likely to be able to adjust their viewing direction and introduce shading devices (such as blinds). The limit of acceptability in this case is more appropriately assessed on the basis of length of time that glare occurs throughout the year although observers greater than 1km away will generally not be affected by small arrays (10m² or less).

3.6.4 Summary of Glare Quantities

Glare is difficult to quantify in terms of intensity. It is easier to determine the period of time that glare occurs for stationary observers (e.g. neighbouring properties within 1km) and the location of the glare source in the field of view for moving observers (e.g. motorists).

To determine the period of time that glare occurs requires a three dimensional assessment for each potentially affected observer. The limit of acceptability should be specified in terms of daily and annual time periods. We would suggest that stationary observers would accept modifying their behaviour if glare impacted on them for no more than 30 minutes per day for not more than 30 days per annum. This results in a total annual glare impact of 15 hours per annum for each single observer point.

A 10m² glare source located in the line of sight of a moving observer should be located a minimum of 75m away from the observer. This would be most likely to occur with a solar panel installed at the end of an inclined road.

3.7 Review of Existing Planning Provisions

3.7.1 Christchurch City Plan

The Christchurch City Plan provides standards for control of glare in Volume 3, Part 11, Section 2. The Plan acknowledges that there are two types of glare that may cause adverse affects – glare from artificial illumination, and reflective glare from structures.

Quantitative zone-based standards are provided for light spill from artificial illumination; however, reflective glare from structures is specifically excluded from these light spill standards. The reason given by the Plan for this approach is that the setting of standards for reflective glare is impracticable because the circumstances under which it may arise are so variable.

Instead, the plan takes a reactive approach to reflective glare, stating in Section 2.5 that particular problems will be dealt with by way of enforcement procedures under Part XII of the Resource Management Act, as and when circumstances require, meaning reflective glare is only likely to be addressed after a structure has been built and a problem has been identified.

It is also noted that the Plan draws special attention to the powers held by the Civil Aviation Authority with respect to lighting that could cause a navigation or safety hazard for aircraft. The Plan recommends that consultation with the Civil Aviation Authority should be undertaken where any development within specific areas around the airport is proposed to include a large scale lighting component. It is considered that this statement should be extended to include large scale solar energy installations, as these would have the potential to create a similar glare hazard to aircraft.

3.7.2 Banks Peninsula District Plan

The Banks Peninsula District Plan does not currently include any provisions that relate directly to reflective solar glare.

3.7.3 Solar Glare Provisions of Other NZ Authorities

Many of the other District Plans in New Zealand address glare, but the majority only address glare in a manner suitable for controlling glare from artificial illumination, rather than reflective solar glare. In these instances, a zone dependant lux limit for light spill is generally specified. This approach is also taken for assessment of glare from artificial illumination in the Christchurch City Plan and the Banks Peninsula District Plan.

Some District Plans do however attempt to address reflective solar glare, and a review of the various provisions is presented in Table 8, below.

Table 9 Summary of Solar Glare Provisions in New Zealand District Plans, as of July 2011

District Council	Summary of Solar Glare Provision
Auckland City	Auckland City Council District Plan states in Rule 6.1.3 that "*Buildings shall be designed and built so that the reflectivity of all external surfaces does not exceed 20% of white light. This means that glass and other materials with reflectivity values that exceed 20% may only be used provided they are covered or screened in such a way that the external surfaces will still meet this rule.*" Although this approach may limit the intensity of glare in some instances, as explained earlier, the reflectivity of materials is usually measured at normal incidence, but as the angle of incidence increase, the reflectivity also increases rapidly. In addition, the occurrence of glare is also dependent not only on the reflectivity of the surface but also on its specularity. As such, this rule may have limited effectiveness in practice.
Clutha District	The Clutha District Plan requires that: "*No building shall be constructed, and/or left unfinished, and/or clad in any protective material or cover which could reflect sufficient light to detract from the amenities of the neighbourhood or cause discomfort to any person resident in the locality. Material used in construction, cladding, or protection of a building where discomfort is likely to occur should have a reflective value not greater than 20%.*" As explained above in the discussion of the Auckland City Council provisions, rules limiting reflectivity alone may have limited effectiveness in practice.
Hauraki District	The District Plan takes a qualitative approach to glare control, stating that: "*In all zones, buildings are to be constructed and finished to ensure reflection (glare) from the building surfaces does not reflect into adjoining properties, or into the vision of motorists on a street or road.*"
Manuwatu - Wanganui	The Plan prescribes the use of painted matt finishes on roofs of industrial buildings within the 60 dB Ldn aircraft noise zone in order to control glare effects on aircraft.
New Plymouth District	The Plan specifies that glare shall be avoided, remedied, or mitigated, and notes that reflective glare is a technically complex issue. No specific rules are provided for reflective and the plan requires assessment to be undertaken on a case by case basis.

District Council	Summary of Solar Glare Provision
Rotorua District	The Rotorua District Plan states in Rule R10.2.4B, which applies to the Rural B1 Zone: "*Reflectivity values for all buildings and structures shall be as follows:* *i) Any exterior surface wall shall have a reflectivity value of between 0 and 37%.* *ii) Any roof shall have a reflectivity value of between 0 and 25%.*" As explained above in the discussion of the Auckland City Council provisions, rules limiting reflectivity alone may have limited effectiveness in practice.
Southland District	The reflective glare provisions of the Southland District Plan are the same as for the Clutha District.
Stratford District	The Stratford District Plan takes a qualitative approach stating in section B2.1.13 that: "*No activity shall emit light (including petrochemical flares), or reflect light, that directly shines from the source into any part of a residential dwelling without the written consent of the owner of that dwelling.*" The wording of the above rule appears to indicate that it could apply to reflective solar glare.
Tararua District	Tararua District Plan states in section 5.4.7.2 that: "*In all Management Areas, buildings are to be constructed and finished in such a manner as to ensure reflection (glare) from the building surfaces does not reflect into adjoining properties or adversely affect the vision of motorists on a street or road.*" The Plan also includes guidance measures that can be taken to control reflective glare, and the matters which should be considered in assessing its impact.
South Taranaki District	The District Plan takes a qualitative approach to glare control, requiring that "*glare produced by reflected sunlight, shall not directly illuminate any part of an adjoining property*".
Wairoa District	The Plan takes a qualitative approach to glare control, stating that: "*No building or structure shall be finished with materials that create a glare nuisance to neighbouring properties or road users.*"
Whakatane District	No specific provisions to control reflective solar glare are included in the plan, but the plan does control the use of solar panels. Under the Plan, solar panels are permitted for domestic dwellings, but are discretionary at commercial scale.
Waipa District	The reflective glare provisions of the Waipa District Plan are the same as for the Clutha District.

3.8 Issues for Consideration

Setting specific design standards for solar installation is difficult because the assumptions needed to generalise the problem may not be particularly relevant to any individual application. The actual installation location, the topography of the land and the location of key observers can vary significantly between different cases. A full reflectivity study for each installation and each key observer point is the only method of determining whether glare occurs and how intense it is.

However, some broad rules could be established for installation location and angle based on the topography and observer points, with a detailed three-dimensional analysis only required if these rules were not adhered to.

3.8.1 Domestic Installations

A glare assessment should be triggered in the following situations:

- The solar panels are installed at an angle greater than 55° from horizontal.
- The solar panels have observers above them and are not installed between the minimum and maximum angles itemised in Appendix D, for the identified observer heights and distances.
- The installation is located adjacent to an airport

An example of this assessment process for residential flat plate collectors is shown below in Figure 24. Note that the figures provided are for illustrative purposes only.

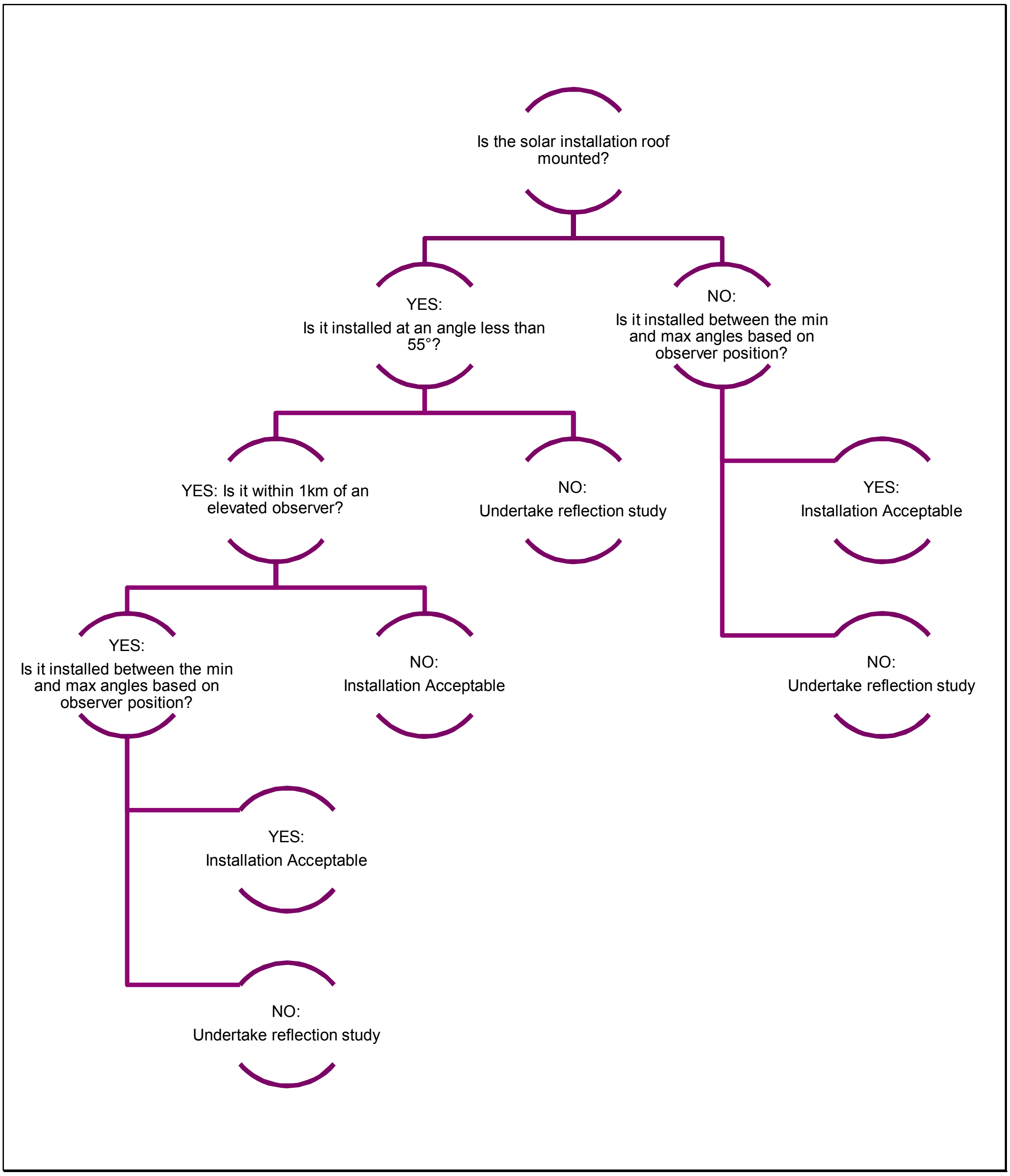


Figure 24 Planning Consent Process for Flat Plate Collectors.

Generally, most domestic installations will comply with these requirements, although glare could still impact on some observers, it is unlikely to occur for a significant amount of time.

If a glare assessment is required it should identify all of the key observer points related to the installation. This should include motorists, pedestrians and neighbouring properties. Any observers which are at risk of glare occurring should be assessed using three dimensional analysis of earth-sun geometry to show when the glare will occur and the duration of the event.

3.8.2 Commercial Installations

A glare assessment should be triggered in the following situations:

- The solar panels are installed at an angle greater than 55° from horizontal.
- The solar panels have observers above them and are not installed between the minimum and maximum angles itemised in Appendix D, for the identified observer heights and distances.
- The installation is located adjacent to an airport

If a glare assessment is required it should identify all of the key observer points related to the installation. This should include motorists, pedestrians and neighbouring properties. Any observers which are at risk of glare should be assessed using three dimensional analysis of earth-sun geometry to show when the glare will occur and the duration of the event.

3.8.3 Solar Concentrators

A glare assessment should be triggered for all solar concentrator installations. This should assess the length of time that any observer will be affected by glare from a misaligned tracking system and the intensity experienced at the observers location. Installations that do not have any key observers (e.g. in a remote location) could be exempt.

3.8.4 Key Observers

The definition of what constitutes a “Key Observer” has only been partially addressed in this report. All observers of glare could be considered “Key Observers” as glare can cause short term (disability) and long term (psychological) impacts. Any observer that would create a health and safety risk if temporarily blinded should be considered.

3.9 Technical Recommendations for Plan Change 63

The following recommendations are provided for Plan Change 63, with respect to control of glare from solar panels:

1) For many scenarios, the potential for reflective solar glare will need to be assessed on a case by case basis. As such, it is recommended that a generic rule should be included in the plan to the effect that solar panel installations shall not cast reflected glare onto any other property so as to cause an unreasonable adverse effect on amenity.
2) In addition, it is recommended that some basic guidance should be given on when the requirement for formal glare assessment should be triggered at the planning stage. It is recommended that this be in the form of some simple screening criteria to establish the likelihood of glare occurring such as those suggested in Sections 3.8.1 to 3.8.3, or a refined version, possibly including a basic calculation that would enable a wider range of situations could be deemed acceptable, reducing the number of scenarios where a formal reflection study might be triggered unnecessarily.
3) If such a screening process is implemented it is recommended that solar energy installations requiring a reflection study should be classified as Discretionary Activities.
4) As explained in the text, it is difficult to set an objective criterion for the amount of glare that may be acceptable in any given situation, due to the number of variables that can affect the degree of impact from glare. It is therefore recommended that guidance should be provided in the plan with respect to the matters which should be given consideration in the assessing the degree of impact from reflective solar glare from any given solar energy installation. These would include the time of day and reflected luminance, period of the year for which the glare occurs, the affected observers and the severity of hazard posed by the glare.
5) The use of provisions that limit reflectivity values are recommended against, as, for the reasons explained in the text, these types of rules are likely to have only limited effectiveness for control of reflective solar glare in practice.

Appendix A

Nomenclature

Appendix A Nomenclature

dB	Decibels or 'A'-weighted Decibels, the units of Sound Pressure Level and Sound Power Level. 'A'-weighting adjusts the levels of frequencies within the sound spectrum to better reflect the sensitivity of the human ear to different frequencies. [Unit: dB]
$L_{A10,T}$	The 'A'-weighted Sound Pressure Level exceeded for 10 percent of the measurement period T. Typically this represents an "average maximum" noise level. [Unit: dB]
$L_{A90,T}$	The 'A'-weighted Sound Pressure Level exceeded for 90 percent of the measurement period T. Typically this represents an "average minimum" noise level, and is often used to represent the background noise level. [Unit: dB]
$L_{Aeq,T}$	The Equivalent Continuous A-weighted Sound Pressure Level measured over the period T. The Equivalent Continuous A-weighted Sound Pressure Level is the constant value of A-weighted Sound Pressure Level for a given period that would be equivalent in sound energy to the time-varying A-Weighted Sound Pressure Level measured over the same period. [Unit: dB]
$L_{AFmax,T}$	The maximum value of A-weighted Sound Pressure Level measured using an 'F' time weighting during the period T. [Unit: dB]
Loudness	The attribute of auditory sensation which describes a listener's ranking of sound in terms of audibility. Usually quantified in terms of Loudness Level.
Loudness Level	A logarithmic measure of Loudness. [Unit: Phon]
Nacelle	The enclosure at the top of the turbine which houses the mechanical equipment such as the rotor bearings, gearbox, generator, oil pumps and cooling equipment.
Pitch Regulation	A method of controlling the power or rotational speed of a wind turbine by varying the pitch angle (angle of attack) of the wind turbine blades.
Phon	The unit of Loudness Level. The Loudness Level of a sound or noise is expressed as *n* Phons when it is judged by binaural listeners, having standard auditory response, to be equal in loudness to a pure tone of frequency 1000 Hz, having the form of a plane progressive wave, coming from directly in front of the listener, at a Sound Pressure Level of *n* dB.
Sound Power Level	A measure of the total sound energy radiated by a source, per unit time. Mathematically, it is ten times the logarithm to the base ten of the ratio of the sound power (W) of the source to the reference sound power; where the reference sound power is 1×10^{-12} W. [Unit: dB]
Sound Pressure Level	A measure of the magnitude of a sound wave. Mathematically, it is twenty times the logarithm to the base ten of the ratio of the root mean square sound pressure at a point in a sound field, to the reference sound pressure; where sound pressure is defined as the alternating component of the pressure (Pa) at the point, and the reference sound pressure is 2×10^{-5} Pa. [Unit: dB]
Spectral Characteristics	Characteristics relating to the frequency content of a sound.
Stall Regulation	A method of controlling the power or rotational speed of a wind turbine through aerodynamic stall of the blades.
Swept Area	The disc shaped area passed through by a wind turbine blade as it rotates, given by $\pi d^2/4$, where d is the rotor diameter.

Temporal Characteristics	Characteristics relating to how the level and frequency content of the sound varies over time.

Appendix B

Table of Selected Wind Turbine Characteristics and Sound Power Levels

Appendix B Table of Selected Wind Turbine Characteristics and Sound Power Levels

Note: In some of the reference reports from which the data below has been taken, the wind speeds are referenced to hub height rather than 10m above ground level (as used by IEC 61400-11). Where this is the case an adjustment has been made to the data to align it with a wind speed reference height of 10m, using the methodology prescribed by IEC 61400-11.

Manufacturer	Model	Rated Power (kW)	Speed Regulation	Configuration	Tower Type	Hub Height (m)	Rotor Diameter (m)	Number of Blades	Rotor RPM	Generator Type	Gearbox Type	Cut-In Wind Speed (m/s)	Rated Wind Speed (m/s)	Cut-Out Wind Speed (m/s)	Sound Power Level for Given Wind Speed (m/s) at 10m Above Ground Level, dB(A)											Max Sound Power Level, dB(A)	Reference
															3	4	5	6	7	8	9	10	11	12	13		
Southwest Windpower	AIR 403	0.4	Aero-elastic stall (flutter)	Horizontal axis, upwind rotor	Guyed or roof mounted	8 to 14	1.15	3		Permanent magnet	Direct drive	3.5	12.5	49						80.9	84.2	86.7	92.9	90.5	97.7	98.0	"Acoustic Tests of Small Wind Turbines", National Renewable Energy Laboratory Report No. NREL/CP-5000-34662, October 2003
Southwest Windpower	AIR X	0.4	Electronic torque control via stall	Horizontal axis, upwind rotor	Guyed or roof mounted	8 to 14	1.15	3		Permanent magnet	Direct drive	3.5	12.5	49	73.1	76.6	78.8	77.7	77.5		81.3	85.2	88.9	90.9	88.8	101.6	"Acoustic Tests of Small Wind Turbines", National Renewable Energy Laboratory Report No. NREL/CP-5000-34662, October 2003
Urban Green Energy	UGE-600	0.6	N/a	Vertical axis	Tubular or roof mount		1.4	3	200 (rated)	Permanent magnet	Planetary	3.5	12	30			68.6	71.6	72.6	75.6	75.6	76.6	76.6	76.6			Test Report No. SCC(10)-700-2-1-10, China CEPREI (Sichuan) Laboratory, January 2010
Southwest Windpower	Whisper H40	0.9	Furling	Horizontal axis, upwind rotor			2.1	3		Permanent magnet brushless	Direct drive	3.4	12.5			82.6	83.8	82.8	83.5	85.3	87.4	91.0	92.4		96.3		"Acoustic Tests of Small Wind Turbines", National Renewable Energy Laboratory Report No. NREL/CP-5000-34662, October 2003
Bergey	XL.1	1	Furling	Horizontal axis, upwind rotor	Tilting monopole	18 to 29	2.5	3		Permanent magnet	Direct drive	3	11	13 (Furling)							75.8	78.7	78.0		80.8		"Acoustic Tests of Small Wind Turbines", National Renewable Energy Laboratory Report No. NREL/CP-5000-34662, October 2003
Urban Green Energy	UGE-1K	1	N/a	Vertical axis	Tubular or roof mount		1.8	3	180 (rated)	Permanent magnet	Planetary	3.5	12	30			69.6	71.6	71.6	74.6	75.6	76.6	77.6	78.6			Test Report No. SCC(10)-700-2-1-10, China CEPREI (Sichuan) Laboratory, January 2010
Zephyr	Airdolphin Mk-0	1	Stall controlled	Horizontal axis, upwind rotor			1.8	3	1250 (rated)	Synchronous, permanent magnet		2.5	12.5	50	72.9	73.8	74.6	75.4	76.2	76.9	77.6	78.3	78.9	79.4	79.9	80.9	Manufacturer Noise Data Sheet. www.energyconnectuk.com/pdf/noisedata.pdf
Mariah	Windspire	1.2	Electronic brake	Vertical axis	Monopole	3.3	1.2	3	420 (max)	Brushless permanent magnet		3.8	10.7	47				82									"Windspire 1.2kw Sound Levels", Windpsire Energy, April 2010
Renewable Devices	Swift	1.5	Angle furling / dynamic brake	Horizontal axis, upwind rotor	Building Mounted or Monopole.	1.8 to 3m above roof level if building mounted. 8m if monopole mounted.	2	5	450 (rated)	Permanent Magnet		3.4	12	14 (Furling)						69							Swift Technical and Planning Pack, SD0037 Part 1, March 2011
Southwest Windpower	Skystream 3.7	2.4	Stall regulated	Horizontal axis, downwind rotor	Guyed or Freestanding Monopole	10.2 to 21	3.72	3	50 to 325	Brushless permanent magnet		3.5	13	63		66.5	71.5	75.0	80.0	82.5	85.0	87.0	87.5	89.5	90.5	91.5	"Sound Testing of Skystream 3.7 Wind Turbine", USDA Argricultrual Research Service, Texas, 2007
Urban Green Energy	UGE-4K	4	N/a	Vertical axis	Tubular or roof mount		3	3	110 (rated)	Permanent magnet	Planetary	3.5	12	30			68.6	71.6	71.6	75.6	75.6	77.6	78.6	78.6			Test Report No. SCC(10)-700-2-1-10, China CEPREI (Sichuan) Laboratory, January 2010
Endurance Wind Power	S Series	5	Stall controlled (constant speed)	Horizontal axis, upwind rotor	Guyed or Freestanding Monopole	28, 31, or 37	6.4	3	166	Induction Generator		4.1	12	24			89.3					93.4					"Endurance Wind Power Acoustic Data Application Note, E-Series / S-Series", Version 1.1, June 2010

Manufacturer	Model	Rated Power (kW)	Speed Regulation	Configuration	Tower Type	Hub Height (m)	Rotor Diameter (m)	Number of Blades	Rotor RPM	Generator Type	Gearbox Type	Cut-In Wind Speed (m/s)	Rated Wind Speed (m/s)	Cut-Out Wind Speed (m/s)	Sound Power Level for Given Wind Speed (m/s) at 10m Above Ground Level, dB(A)											Max Sound Power Level, dB(A)	Reference
															3	4	5	6	7	8	9	10	11	12	13		
Evance	R9000	5	Pitch Regulated	Horizontal axis, upwind rotor	Monopole or Tilt Pole	10, 12, 15, or 18	5.5	3	200 (nom)	Permanent magnet brushless	Direct drive	3	12	60	78.5	80.6	82.7	84.8	86.9	89.0	91.1	93.2	95.3	97.4			Evance R9000 Performance Data Sheet No.SM0175-01
Eoltec	Scirocco	6	Centrifugal stall control	Horizontal axis, upwind rotor	Guyed monopole tilting	18, 24, or 30	5.6	2	80 to 245	Synchronous permanent magnet	Direct drive	2.7	12	60		73.3	76.8	79.5	81.7	83.9	85.8	87.8					"Eoltec Scirocco 5.6m/6kW Wind Turbine: Source Noise Level Measurement", Hayes Mackenzie Report No. HM: 1820/R1, Version 1.3, April 2007
Proven Energy	Proven 11 (WT6000)	6	Passive pitch control	Horizontal axis, downwind rotor	Monopole or Tilt Pole	9 or 15	5.6	3	200 (rated)	Permanent magnet brushless	Direct drive	2.5	12				73.5			85.4						93.5	"Proven WT6000 Wind Turbine Noise Emission Report", Aeolus Power.
Quiet Revolution	QR5	6	N/a	Vertical axis	Monopole or roof mount	18	3.1	3	300 (max)	Permanent magnet	Direct drive	5	14	19				84.2	86.7	88.4	90.2	92.1					"Wind Turbine Noise Measurements", ISVR Consulting, Report No. 7837-R01, December 2007
Abundant Renewable Energy	ARE 442	10	Stall controlled with furling	Horizontal axis, upwind rotor	Lattice	30.5	7.2	3	140 (rated)	Permanent Magnet	Direct drive	2.5	12	25		85.8	85.9	85.2	84.9	87.6	89.9	93.7	96.5	98.2			"Wind Turbine Generator System Acoustic Noise Test Report for the ARE 442 Wind Turbine", National Renewable Energy Laboratory Technical Report No. NREL/TP-5000-49179, November 2010
Bergey	Excel (Old Model with BW03 Airfoils)	10	Furling	Horizontal axis, upwind rotor	Guyed lattice or freestanding monopole	18 to 43	7	3		Permanent magnet	Direct drive	2.5	12	15.6 (Furling)			87.2	91.0	96.1	99.5	102.2	105.4	107.6	109.8	112.2		"Acoustic Tests of Small Wind Turbines", National Renewable Energy Laboratory Report No. NREL/CP-5000-34662, October 2003
Bergey	Excel (with SH3052 Airfoils)	10	Furling	Horizontal axis, upwind rotor	Guyed lattice or freestanding monopole	18 to 43	7	3		Permanent magnet	Direct drive	2.5	12	15.6 (Furling)					90.7	90.7	92.3	93.4	95.1	96.9	99.0	101.5	"Acoustic Tests of Small Wind Turbines", National Renewable Energy Laboratory Report No. NREL/CP-5000-34662, October 2003
Bergey	Excel-S (2009 Model)	10	Furling	Horizontal axis, upwind rotor	Guyed lattice or freestanding monopole	18 to 43	7	3		Permanent magnet	Direct drive	2.5	12	15.6 (Furling)		78.5	79.9	80.4	82.6	84.9	88.0	91.0	94.8	98.8	101.9		"Acoustic Chracteristics of the Beergey Excel-S 10kW Wind Turbine", USDA Agricultrual Research Service, Texas, June 2010
Gaia Wind Power	Gaia-11kW	11	Passive stall	Horizontal axis, upwind rotor	Lattice or Tubular	18	13	2	56 (nom)		2-Stage	3.5	9.5	25				83.7	85	86	87.3	88.2	89.1				"Small Wind Turbine Testing Results from the National Renewable Energy Laboratory", NREL/CP-500-48089, April 2010.
Proven Energy	Proven 35-2	12	Passive pitch control	Horizontal axis, downwind rotor	Monopole or Tilt Pole	15, 20, or 25	8.5	3		Permanent magnet brushless	Direct drive	3.5	11	54			84.1	87.8	91.2	94.2	96.9	99.2	101.1	102.8	104.0	105.4	"Little laight, Cairnryan, Stranraer, Proven P35-2 Wind Turbine Noise Perrformance Test", Hayes Mackenzie Report No. HM: 2264/R1, Version 2.0, Sept 2010
Endurance Wind Power	E Series	50	Stall controlled (constant speed)	Horizontal axis, downwind rotor	Monopole or Lattice	31, 37, or 43	19.2	3	42	Induction Generator		3.5	9.5	25			92.1					94.8					"Endurance Wind Power Acoustic Data Application Note, E-Series / S-Series", Version 1.1, June 2010
Entegrity	EW50	50	Passive stall	Horizontal axis, downwind rotor	Monopole or lattice	24, 30, or 36	15	3	65 (rated)	Asynchronous	Planetary	4	11.3	22.4			100.5	102.3	103.6	104.7	105.7	106.5	107.2	107.8			"Small Wind Turbine Testing Results from the National Renewable Energy Laboratory", NREL/CP-500-48089, April 2010.
Seaforth	AOC 15/50	50	Stall controlled	Horizontal axis, downwind rotor	Monopole or Lattice	30.5	15	3	62 (rated)	3-Phase Asynchronous Induction	2-Stage Planetary	4.9	12	22.4		96.9	96.9	100.1	100.8		101.9						"Acoustic Tests of Small Wind Turbines", National Renewable Energy Laboratory Report No. NREL/CP-5000-34662, October 2003

Manufacturer	Model	Rated Power (kW)	Speed Regulation	Configuration	Tower Type	Hub Height (m)	Rotor Diameter (m)	Number of Blades	Rotor RPM	Generator Type	Gearbox Type	Cut-In Wind Speed (m/s)	Rated Wind Speed (m/s)	Cut-Out Wind Speed (m/s)	Sound Power Level for Given Wind Speed (m/s) at 10m Above Ground Level, dB(A)											Max Sound Power Level, dB(A)	Reference
															3	4	5	6	7	8	9	10	11	12	13		
Lagerwey	18/80	80	Passive blade pitch adjustment	Horizontal axis, upwind rotor	Tubular	32	18	2	50 to 120	Induction		3	12	25												92.9	"Wind Turbine Replacement Options Study", Department of Mechanical and Industrial Engineering, University of Massachusetts, 1999.
Northern Power Systems	North Wind 100	100	Stall controlled variable speed	Horizontal axis, upwind rotor		30 or 37	21	3	59 (max)	Permanent magnet	Direct drive	3.5	14.5	25				89.6	91.9	93.9	95.1	97.0	98.1	99.6	100.8		"Acoustic Tests of Small Wind Turbines", National Renewable Energy Laboratory Report No. NREL/CP-5000-34662, October 2003
Nordex	N27/150	150	Stall regulated	Horizontal axis, upwind rotor	Tubular or Lattice	31.5, 40.5, or 50.5	27	3	26 to 59.3	Dual winding	3-Stage Helical	3	10.5	25												99	"Wind Turbine Replacement Options Study", Department of Mechanical and Industrial Engineering, University of Massachusetts, 1999.
Micon	M700-225	225	Stall regulated	Horizontal axis, upwind rotor	Tubular	30 or 36	29.8	3		Induction	Helical	3	18	25												101.1	"Wind Turbine Replacement Options Study", Department of Mechanical and Industrial Engineering, University of Massachusetts, 1999.
Vestas	V29-225	225	Pitch Regulated	Horizontal axis, upwind rotor	Tubular	32	29	3	40.5	Double wound induction	2-Stage Spur	4	14	25			96.4	96.9	97.3	97.8	98.2					98.2	Vestas General Specification, V29-225kW 50Hz Turbine, 1996.
Lagerwey	30/250	250	Passive blade pitch adjustment	Horizontal axis, upwind rotor	Tubular	41	30	2	35 to 70	Induction	Helical / spur	3	12	25												98.7	"Wind Turbine Replacement Options Study", Department of Mechanical and Industrial Engineering, University of Massachusetts, 1999.
Nordex	N29/250	250	Stall regulated	Horizontal axis, upwind rotor	Tubular or Lattice	30, 40, or 50	29.7	3	39.5	Double wound induction		3	15.5	25												101.7	"Wind Turbine Replacement Options Study", Department of Mechanical and Industrial Engineering, University of Massachusetts, 1999.
Windflow	Windflow 500	500	Pitch Regulated	Horizontal axis, upwind rotor	Tubular	30	33.2	2	48 to 51	Synchronous	Planetary / parallel torque limiting gearbox	5.5	13.7	30				101.8	102.4	103.3	104.6	106.2					"Windflow 500 Sound Power Levels", Test Report, Hegley Acoustic Consultants, May 2009
Bonus	B44/600	600	Stall regulated	Horizontal axis, upwind rotor	Tubular	40, 50, or 58	44	3	27	Asynchronous	Spur / Planetary	3	15	25						100							Manufacturer data quoted in "Proposed Wind Farm at Mount Stuart Assessment of Noise Effects", NZ Windfarms Ltd,
Enercon	E40/6.44	600	Pitch Regulated	Horizontal axis, upwind rotor	Tubular		44	3	18 to 34	Synchronous ring generator	Direct drive	2.5	12	34						100							Manufacturer data quoted in "Proposed Wind Farm at Mount Stuart Assessment of Noise Effects", NZ Windfarms Ltd,
Fuhrlander	FL 600	600	Pitch Regulated	Horizontal axis, upwind rotor	Tubular	50 to 75	50	3	13 to 26	Double fed induction	3-Stage	3	10.8	20						100.7							Manufacturer data quoted in "Proposed Wind Farm at Mount Stuart Assessment of Noise Effects", NZ Windfarms Ltd,
Vestas	V44-600	600	Pitch Regulated	Horizontal axis, upwind rotor	Tubular	35, 40, 45, 50, or 55	44	3	28			5	17	20												99.5	Vestas Product Data, 1996.
Vestas	V47-660kW	660	Pitch Regulated	Horizontal axis, upwind rotor	Tubular	40, 45, 50, or 55	47	3	28.5	Asynchronous	Planetary	4	16	25				99.9	100.4	100.8	101.3	101.7					Vestas Product Data, 1997. Hub height 47.5m.
Vestas	V52-850kW	850	Pitch Regulated with Variable Speed	Horizontal axis, upwind rotor	Tubular	44, 49, 54, 55, 65, or 74	52	3	14.0 to 31.4	4-Pole doubly fed generator	One planetary stage and two helical stages	4	18	25		92.5	95.8	98.7	99.3	100	100.7	101.3	101.6	102.2			Vestas Product Brochure. Mode 0 Operation (Full Power).

Manufacturer	Model	Rated Power (kW)	Speed Regulation	Configuration	Tower Type	Hub Height (m)	Rotor Diameter (m)	Number of Blades	Rotor RPM	Generator Type	Gearbox Type	Cut-In Wind Speed (m/s)	Rated Wind Speed (m/s)	Cut-Out Wind Speed (m/s)	Sound Power Level for Given Wind Speed (m/s) at 10m Above Ground Level, dB(A)											Max Sound Power Level, dB(A)	Reference
															3	4	5	6	7	8	9	10	11	12	13		
Acciona	AW-82/1500	1500	Pitch Regulated	Horizontal axis, upwind rotor	Tubular	80	82	3	16.7 (nom)		4-Stage Gearbox	3	10.5	20				101.7	102.5	102.2	101.8	101.5					Acciona Product Data.
NEG Micon	NM82-1650	1650	Active Stall	Horizontal axis, upwind rotor	Tubular	59, 68.5, 70, or 78	82	3	14.4	One-speed water cooled.	One planetary stage and two helical stages	3.5	13	20	100.4	100.9	101.1	101.3	101.9	102.9	103.1					103.3	NEG Micon Manufacturer Data, 2004. Hub height 59m.
Vestas	V100-1.8MW	1800	Pitch Regulated with Variable Speed	Horizontal axis, upwind rotor	Tubular	80, 95, or 125	100	3	14.9 (nom)	Permanent Magnet	One planetary stage and two helical stages	3	12	20												105.0	Vestas Product Brochure. Mode 0 Operation (Full Power). 80m Hub Height.
Enercon	E70	2000	Pitch Regulated with Variable Speed	Horizontal axis, upwind rotor	Tubular	64 to 113	71	3	6 to 21.5	Synchronous, direct drive annular	Direct drive	2.5	13.5	34												102	Alberts, D.J., "Primer for Addressing Wind Turbine Noise", Lawrence University, October 2006
Enercon	E82 E2	2000	Pitch Regulated with Variable Speed	Horizontal axis, upwind rotor	Tubular	78, 85, 98, 108, or 138	82	3	6 to 18	Synchronous, direct drive annular	Direct drive	2.5	13	34			97.2	101.6	103.5	103.5	103.5	103.5					Enercon Sound Power Level Data, April 2010. Full Power Mode. 98m Hub Height.
Gamesa	G90	2000	Pitch Regulated	Horizontal axis, upwind rotor	Tubular	67, 78, or 100	90	3	9 to 19	Doubly fed	1 planetary stage / 2 parallel stages	3	17	21	95	98.5	103.3	107.3	108.4	108.4	108.4						Gamesa Wind, "G90 2MW 50/60 Hz Power Curve and Noise Emission," Document GD022915-en, April 2009. Hub height 100m.
Vestas	V100-2.0MW GridStreamer	2000	Pitch Regulated with Variable Speed	Horizontal axis, upwind rotor	Tubular	80 or 95	100	3	14.9 (nom)	Permanent Magnet	One planetary stage and two helical stages	3	12.5	20												105.5	Vestas Product Brochure. Mode 0 Operation (Full Power). 80m Hub Height.
Vestas	V80-2.0MW	2000	Pitch Regulated with Variable Speed	Horizontal axis, upwind rotor	Tubular	60, 67, 78, 80, or 100	80	3	10.8 to 19.1	4-Pole doubly fed generator	Two planetary stages and one helical stage	4	16	25		93.0	97.2	97.4	97.6	97.8	98.5	99.3	100.7	101.0			Vestas Product Brochure. Mode 0 Operation (Full Power).
Vestas	V90-1.8/2.0MW	2000	Pitch Regulated with Variable Speed	Horizontal axis, upwind rotor	Tubular	80, 95, 105, or 125	90	3	14.5 (nom)	4-Pole doubly fed generator	Two planetary stages and one helical stage	4	12	25												104	Vestas Product Brochure. Mode 0 Operation (Full Power). 80m Hub Height.

Manufacturer	Model	Rated Power (kW)	Speed Regulation	Configuration	Tower Type	Hub Height (m)	Rotor Diameter (m)	Number of Blades	Rotor RPM	Generator Type	Gearbox Type	Cut-In Wind Speed (m/s)	Rated Wind Speed (m/s)	Cut-Out Wind Speed (m/s)	Sound Power Level for Given Wind Speed (m/s) at 10m Above Ground Level, dB(A)											Max Sound Power Level, dB(A)	Reference
															3	4	5	6	7	8	9	10	11	12	13		
REpower	MM82	2050	Pitch Regulated	Horizontal axis, upwind rotor	Tubular	59, 80, or 100	82	3	8.5 to 17.1	Asynchronous double fed induction	3-Stage Spur / Planetary	3.5	14.5	25	90	94	100.5	102.5	103.5	104.5	105	105				105	REpower Test Report No. SD-2.2-WT.SL-1-B-EN, September 2005. Hub height 80m.
REpower	MM92	2050	Pitch Regulated	Horizontal axis, upwind rotor	Tubular	68.5, 78.5, 80, or 100	92.5	3	7.8 to 15.0	Asynchronous double fed induction	Spur / Planetary	3	12.5	24	90.4	94.4	100.3	103	104.1	105	105	105				105	REpower Test Report No. SD-2.9-WT.SL-1-A-EN, May 2005. Hub Height 80m.
Siemens	SWT-2.3-101	2300	Pitch Regulated with Variable Speed	Horizontal axis, upwind rotor	Tubular	80 or site specific	101	3	6 to 16	Asynchronous	3-Stage Planetary / Helical	4	12	25		95.7	100.6	105.4	106.0	106.0	106.0	106.0	106.0	106.0	106.0	106.0	Siemens Product Brochure, 2010. Hub height 99.5m. Standard Mode of Operation.
Siemens	SWT-2.3-82 VS	2300	Pitch Regulated	Horizontal axis, upwind rotor	Tubular	80	82.4	3	6 to 18	Asynchronous	3-Stage Planetary / Helical	3	13	25		91	97	102	105	106	106	106	106	106	106	106	Siemens Test Report No. PG-03-10-0000-0071-02, October 2008. Hub height 80m.
Siemens	SWT-2.3-93	2300	Pitch Regulated	Horizontal axis, upwind rotor	Tubular	60	93	3	6 to 16	Asynchronous	3-Stage Planetary / Helical	4	13	25				105	107	107	107	107					Siemens Test Report No. PG-03-10-0000-0103-00, March 2007. Hub height 80m.
Mitsubishi	MWT-95	2400	Pitch Regulated	Horizontal axis, upwind rotor	Tubular	80	95	3	9.0 to 16.9	Asynchronous		3	12.5	25				106.9	107.6	107.9	107.8	105.5					Manufacturer Data.
Nordex	N100	2500	Pitch Regulated with Variable Speed	Horizontal axis, upwind rotor	Tubular	100	99.8	3	9.6 to 14.9	Double fed asynchronous	Planetary / Spur	3	12.5	20	98.5	100.5	103.3	106.1	107.4	107.5	107.5	107.5					Manufacturer Data.
Nordex	N80	2500	Pitch Regulated	Horizontal axis, upwind rotor	Tubular	60	80	3	10.8 to 18.9	Double fed asynchronous	Spur / Planetary	3	15	25		98.0	100.5	102.5	103.0	103.5	104.0	104.0	104.5	105.0			Nordex Test Report No. F008_149_A03_EN, July 2007
Nordex	N90/2500 HS	2500	Pitch Regulated	Horizontal axis, upwind rotor	Tubular	65 or 80	90	3	9.6 to 16.9	Asynchronous double fed induction	3-Stage Spur / Planetary	3	16.1	25	95.0	99.0	102.5	105.5	106.5	107.0	107.0	107.0	107.0	107.0			Nordex Test Report No. F008_149_A03_EN, July 2007
Vestas	V100-2.6MW	2600	Pitch Regulated with Variable Speed	Horizontal axis, upwind rotor	Tubular	80	100	3	6.7 to 13.4	4-Pole doubly fed generator	Two planetary stages and one helical stage	3	12.5	23	96.7	98.1	101.2	104.3	104.4	104.2	104.1						Vestas Product Brochure. Mode 0 Operation (Full Power). 80m Hub Height.
Vestas	V90-3.0MW	3000	Pitch Regulated with Variable Speed	Horizontal axis, upwind rotor	Tubular	65, 80, or 105	90	3	8.6 to 18.4	4-Pole doubly fed generator	Two planetary stages and one helical stage	3.5	15	25		97.9	100.9	104.2	106.1	107	106.9	105.6	105.2	105.3	105.4		Vestas General Specification. Mode 0 Operation (Full Power). 80m Hub Height.
Vestas	V112-3.0MW	3075	Pitch Regulated with Variable Speed	Horizontal axis, upwind rotor	Tubular	84, 94, or 119	112	3	6.2 to 17.7	Permanent Magnet	4-Stage Planetary / Helical	3	13	25	94.7	97.3	100.9	104.3	106.0	106.5							Vestas Product Brochure. Mode 0 Operation (Full Power). 84m Hub Height.

Manufacturer	Model	Rated Power (kW)	Speed Regulation	Configuration	Tower Type	Hub Height (m)	Rotor Diameter (m)	Number of Blades	Rotor RPM	Generator Type	Gearbox Type	Cut-In Wind Speed (m/s)	Rated Wind Speed (m/s)	Cut-Out Wind Speed (m/s)	Sound Power Level for Given Wind Speed (m/s) at 10m Above Ground Level, dB(A)											Max Sound Power Level, dB(A)	Reference
															3	4	5	6	7	8	9	10	11	12	13		
Enercon	E112	4500	Pitch Regulated with Variable Speed	Horizontal axis, upwind rotor	Tubular	124	114	3	8 to 13	Synchronous, direct drive annular	Direct drive	2.5	13	34												107	Alberts, D.J., "Primer for Addressing Wind Turbine Noise", Lawrence University, October 2006

Appendix C

Comparison of Wind Turbine Noise Assessment Methods used in Australia

Comparison of compliance results obtained from the various wind farm standards used in Australia

Jonathan Cooper (1), Tom Evans (1) and Luis Najera (2)

(1) AECOM, Level 28, 91 King William Street, Adelaide, South Australia 5000
(2) AECOM, Level 8, 540 Wickham Street, Fortitude Valley, Queensland 4006

ABSTRACT

There are a number of standards and guidelines which are used in Australia for the assessment of wind farm noise. While there is some variation in the lower noise limit applied, the standards and guidelines typically set noise criteria for wind farms as 40 dB(A) or the background noise level + 5 dB(A), whichever is the greater. Additionally, they provide different methods for measuring compliance once the wind farm is operational. This paper examines the differences that result when assessing compliance against the various measurement and analysis procedures. Compliance measurements from a number of receivers surrounding several wind farm sites are used in the analysis. Differences of between 1.9 and 4.3 dB(A) are observed between the highest and lowest assessment results obtained at individual receivers, although this range is reduced to 1.9 - 2.7 dB(A) when L_{Aeq} results that appeared to be influenced by extraneous noise are discarded. These results complement the findings of our other paper which compares predicted levels against the compliance measurement results, and can be used to compare predictions against wind turbine noise levels measured and analysed using different methodologies.

INTRODUCTION

In recent years there has been significant growth in wind farm electricity generation across Australia. The current national focus on renewable energy and greenhouse gas emissions reduction is likely to maintain or result in increased growth in this sector.

There are a number of standards and guidelines which are used or are intended to be used in Australia for the assessment of wind farm noise. These include, but are not limited to; the South Australian *Wind farms environmental noise guidelines* 2009 (SA EPA, 2009), the South Australian *Wind Farms Environmental Noise Guidelines* 2003 (SA EPA, 2003), Australian Standard 4959:2010 (AS 4959:2010), New Zealand Standard 6808:2010 (NZS 6808:2010), New Zealand Standard 6808:1998 (NZS 6808:1998), and the currently draft *National Wind Farm Development Guidelines* (EPHC, 2010).

A detailed discussion of the slightly different approaches used to set noise criteria for wind farms is beyond the scope of this paper, but the standards and guidelines typically set noise criteria for wind farms to be achieved at sensitive receivers as 40 dB(A) or the background noise level + 5 dB(A), whichever is the greater.

Once noise criteria have been established for a proposed wind farm development it is the acoustic engineer's task to provide detailed wind turbine noise level predictions at the noise sensitive receivers around the site. Following the completion of construction, compliance noise measurements are undertaken at the nearest noise sensitive receivers to confirm compliance with the relevant standard or guideline.

It is important that noise levels are accurately predicted at the design stage. Under-prediction of noise levels may result in failure to meet the noise criteria and the expensive shut down of wind turbines, while overly conservative modelling curtails renewable energy generation and reduces the size, and potentially the financial viability, of wind farm developments.

The standards and guidelines used to assess wind farm developments provide different methods for measuring and analysing operational noise levels at the completion of construction. These differences between the measurement methods result in differences in the measured noise level and can therefore potentially affect whether or not compliance with the noise criteria is achieved.

This paper assesses the magnitude of differences that result when assessing compliance measurements using the various measurement procedures. Compliance measurements from a number of residences surrounding four wind farm sites are used in the analysis. When selecting data for analysis, particular focus was placed on using measurement data from locations where wind turbine noise was the dominant noise source, to minimise the influence of background noise on the findings.

This paper complements the finding of our paper titled 'Comparison of predicted and measured wind farm noise levels and implications for assessments of new wind farms' (Evans and Cooper, 2011), which is also presented at this conference. Together they can be used to compare the accuracy of a number of wind turbine noise prediction methods to compliance monitoring results obtained from a variety of compliance measurement and analysis procedures.

STANDARDS USED IN AUSTRALIA

Several different standards and guidelines are used to assess wind farm noise in Australia. The compliance measurement and analysis requirements of these standards are summarised below.

South Australian Wind farms environmental noise guidelines 2009

The South Australian *Wind farms environmental noise guidelines* 2009 (2009 SA Guidelines) were developed by the South Australian Environment Protection Authority (EPA).

The 2009 SA Guidelines require that the $L_{A90,10min}$ noise level is measured over the range of wind speeds from cut-in speed to the speed of the rated power of the turbines at a minimum. The data is to cover at least 2000 intervals, with at least 500 intervals corresponding to the worst case wind direction.

The worst case wind direction is defined as wind directions within 45° of downwind of the nearest wind turbine to the measurement site. The compliance assessment is based on only the data measured under the worst case wind direction – all data from other directions is excluded from the compliance assessment. A polynomial regression analysis is undertaken to determine the measured wind turbine noise level, with correction for the previously measured background noise data applied if required.

Where the above method proves unsuitable for compliance checking the 2009 SA Guidelines allow for alternative techniques to be employed, following discussions with the EPA. Suggested alternatives include attended measurements with periodical shutdown of wind turbines if required.

South Australian Wind farms environmental noise guidelines 2003

The South Australian *Wind farms environmental noise guidelines* 2003 (2003 SA Guidelines) were an earlier version of the 2009 SA Guidelines and were also developed by the South Australian EPA. The 2003 SA Guidelines are still used in some States to assess wind farm noise.

Both the 2003 and 2009 SA Guidelines use L_{A90} levels measured under downwind conditions to assess compliance of the wind farm. The compliance result achieved by the two methods should therefore be the same, such that they are not separately assessed in this paper.

New Zealand Standard 6808:2010

New Zealand Standard 6808:2010 *Acoustics – Wind farm noise* (NZS 6808:2010) was recently adopted in Victoria.

NZS 6808:2010 expects that at least 10 days (1440 data points) of compliance measurements are undertaken, with data gathered over the range of wind speeds and directions normally expected at the wind farm. The $L_{A90,10min}$ noise level is measured over this 10 day period.

Unlike the 2009 SA Guidelines, there is no specific requirement to exclude data points outside the downwind direction. However, if the initial background noise measurements indicate a significant difference in the pre-construction noise levels under different wind directions or times of day, noise criteria may be set based on particular wind directions or times of day. There is chance that this difference in pre-construction background noise levels might be noted for a downwind direction, so there is some potential for an unintended downwind compliance measurement to be taken. Additionally, there is a chance that the wind that occurs during the compliance measurements is from predominantly downwind directions.

However, for the purposes of our investigation it has been assumed that all directions are assessed together.

NZS 6808:2010 provides the site operator with the option of taking attended 'on/off' compliance measurements at receivers if appropriate, but a review of the results from on/off testing is not included in this paper.

New Zealand Standard 6808:1998

New Zealand Standard 6808:1998 *Acoustics – The assessment and measurement of sound from wind turbine generators* (NZS 6808:1998) was used to set noise criteria for new wind farm applications in Victoria until March 2011.

The key difference in the compliance measurement method outlined in NZS 6808:1998 (as compared to NZS 6808:2010) is that $L_{A95,10min}$ levels are used rather than $L_{A90,10min}$ levels. Like the 2010 standard, NZS 6808:1998 potentially requires compliance measurements under different wind directions and times of day.

While not intended by the standard, Planning Permits issued for wind farms in Victoria have typically included the requirement that compliance is assessed separately for the "all-time" (24 hours) and night time (10pm – 7am) period. The requirements for downwind, and 90° sector analysis have also been previously included in Planning Permits although this is not specifically required under NZS 6808:1998 (Delaire and Griffin, 2011).

Australian Standard 4959:2010

Australian Standard 4959:2010 *Acoustics – Measurement prediction and assessment of noise from wind turbine generators* (AS 4959:2010) has been recently introduced.

AS 4959:2010 is the only standard that requires that the L_{Aeq} noise level from the wind farm is assessed against the predetermined noise criteria. It outlines two possible methodologies that might be used for compliance testing, but notes that the method used should be agreed with the Relevant Authority prior to the commencement of testing.

Methodology 1 included in the Standard follows the same approach as the background noise measurements, with approximately 2000 representative measurements to be collected. The standard leaves many assessment decisions, such as the speeds and directions to be assessed, to the Relevant Regulatory Authority, but notes that:

> Generally, data collected when the wind direction is from the wind farm to the receiver would be the data of primary interest to the Relevant Regulatory Authority.

In acknowledgment of the difficulty of measuring L_{Aeq} compliance levels directly without contribution from extraneous noise sources, Methodology 1 of the Standard requires the measurement of the L_{A90} noise level, with a numerical addition of a minimum of 1.5 dB added to each measurement to account for the expected difference between the wind farm L_{Aeq} and L_{A90} levels. Methodology 1 considers that all noise measured at the receiver is the result of noise from the wind turbines, with no allowance provided to correct for background noise. The standard notes that this method is likely to be a conservative method.

For the purposes of our assessment we have assumed that the Relevant Regulatory Authority has required compliance measurements are taken under downwind conditions, with a direction tolerance of ±45°.

Methodology 2 provided by the standard requires the use of attended noise measurements at one noise sensitive receiver, to validate prediction model outputs and therefore compliance with criteria at the other receivers. At least ten 10-minute L_{Aeq} measurements are required both above and below the 'critical' wind speed, with the attended measurements to extend to speeds at least 3m/s above and below the 'critical' wind speed. Attended L_{Aeq} measurements with the wind turbines turned off may be used to correct for the influence of background noise if necessary.

While this paper presents no results from attended measurements we provide some comment on the suitability of Methodology 2 for determining compliance at all receivers around a wind farm.

Draft National Guidelines July 2010

The draft *National Wind Farm Development Guidelines* (Draft National Guidelines) were introduced for a 12 month trial in July 2010. The Draft National Guidelines suggest that initially Methodology 1 of AS 4959:2010 is used for compliance measurements. Where compliance is unclear from those measurements and it is suspected this is as a result of background noise, it is recommended that the same measurement procedure is to be followed, but repeated at a 'secondary location'. The secondary location is a location selected near the receiver that is the same distance from the same wind turbines, where the geographical setting and predicted noise level is the same as the original location, but is further from extraneous noise sources.

Where it is not possible or practical to confirm compliance through measurements at a secondary location, attended measurements using Methodology 2 of AS 4959:2010 are recommended. However, it is important to note that the Draft National Guidelines use attended measurements at each problematic receiver, rather than trying to use measurements at one receiver to confirm the accuracy of noise predictions and compliance at other receivers like AS 4959:2010.

In extreme cases where none of the above methods are able to demonstrate that compliance is achieved but the Relevant Authority agrees that compliance is likely to be achieved, the Draft National Guidelines suggest 'derived point measurements'. Derived point measurements use measurement results at a location closer to the wind farm where noise levels are clearly controlled by wind farm noise to calibrate the noise model.

As the Draft National Guidelines initially follow Methodology 1 of AS 4959 they are not separately assessed in this paper. However, comment on the suitability of the secondary methodologies suggested by the Guidelines is provided.

Summary of assessment methods

The key requirements of the various assessment methods considered in our analysis are presented in Table 1

Table 1. Summary of compliance assessment methods

Method	*Descriptor*	*Wind direction*
SA Guidelines	L_{A90}	Downwind
NZS 6808:2010	L_{A90}	All
NZS 6808:1998	L_{A95}	All
AS 4959	L_{Aeq}	Downwind

We note that wind direction used during the AS 4959:2010 compliance assessment methodology is to be determined by the Relevant Regulatory Authority. For the purposes of our assessment it has been assumed that the Authority has requested that a downwind assessment is undertaken to provide more direct comparison to the 2009 SA Guidelines.

SITE DESCRIPTIONS

Four wind farm locations and ten measurement sites have been selected for comparison in this paper as the measurements collected at these wind farms appear to be controlled by noise from the wind turbines across a reasonable wind speed range.

The measurement sites are typically representative of the closest receivers to wind farms in South Australia, although we note that several of the measurement sites were not actually in the vicinity of a noise sensitive receiver. Turbine noise levels at the measurement sites are generally higher than noise levels at typical receivers adjacent to wind farms. While this restricts the range of distances at which measured and predicted noise levels are compared in this paper, the sites are representative of the distances at which actual noise levels from turbines are between approximately 35 and 40 dB(A), where noise from a wind farm represents a design constraint.

For commercial reasons, the names and locations of the wind farms have not been disclosed and the wind farms will be designated as Wind Farm A through to D. Based on compliance monitoring conducted at each site, all of these wind farms are in compliance with the environmental noise criteria. A description of each wind farm is presented in the following sections.

Wind Farm A

Wind Farm A involves a line of turbines (approximately 2 MW) stretching for about 10 kilometres along the top of a range of hills. The turbines are spaced approximately 400 metres apart from each other. Three noise measurement sites have been considered as part of this comparison and have been designated A1, A2 and A3. Each of the measurement sites are located between 800 and 1000 metres from the nearest turbine, and are situated 50 to 70 metres lower than the base height of that turbine.

Wind Farm B

Wind Farm B also involves a line of turbines (approximately 2 MW) stretching for about 10 kilometres along the top of a range of hills. The turbines are spaced approximately 300 metres apart from each other. Three noise measurement sites have been considered as part of this comparison and have been designated B1, B2 and B3. The measurement sites are located between 900 and 1,700 metres from the nearest turbine, and are situated 130 to 200 metres lower than the base height of that turbine.

Wind Farm C

Wind Farm C involves a group of turbines (approximately 1.5 MW) distributed over an area of about 20 square kilometres. The turbines are spaced approximately 350 metres apart from each other. Four noise measurement sites have been considered as part of this comparison and have been designated C1, C2 and C3. The measurement sites are located between 300 and 900 metres from the nearest turbine.

Wind Farm D

Wind Farm D involves a line of turbines (approximately 1.5 MW) stretching over about seven kilometres. The turbines are spaced approximately 250 to 400 metres apart from each other. One noise measurement site has been selected for this comparison and has been designated D1. The measurement site is located approximately 350 metres from the nearest turbine but is also located approximately 800 metres from another four turbines from another direction.

NOISE MEASUREMENT PROCEDURE

A-weighted $L_{eq,10min}$, $L_{90,10min}$ and $L_{95,10min}$ noise levels from the operational wind farms were logged at each of the measurement sites over a period of three to four weeks. Class 2 noise monitoring equipment was used at each of the sites and the calibration checked both before and after the measurement period to check that no significant drift had occurred. The microphone was located at 1.2 to 1.5 metres above ground and fitted with a 90 mm thick windshield, which was adequate to reduce the influence of wind-induced noise on the measurement (Cooper, Leclercq and Stead, 2010).

Measurements that were obviously affected by extraneous noise sources or that did not coincide with wind speeds between the cut-in and cut-out of the turbines were excluded from the analysis. For certain situations, the measurements were filtered based on wind direction when results for specific wind directions were required, e.g. for the 2009 SA Guidelines. Following the removal of data points, between 2000 and 4000 data points remained at the various measurement sites for the situations where all wind directions were being considered. For those situations where only a single wind direction ±45º was considered, between 200 and 1000 data points remained at the various measurement sites. Where less than 500 data points remained at a particular wind speed, these were confined mainly to the small range of wind speeds where site measured sound power data was available.

The measured noise levels were correlated with wind speeds for the period, measured at the most representative hub height meteorological mast. A single "measured" noise level value for each integer wind speed was then determined by fitting a polynomial regression line to the data.

A significant issue that can affect measurement results from operational wind farms is the contribution of the background noise environment to the overall measured level. While this can be somewhat overcome by subtracting the measured pre-construction noise levels from the measurements, this method is susceptible to error as background noise levels have been shown to change across seasons and years (Delaire and Walsh, 2009), and because of differences between pre- and post-construction measurement locations.

To address this, each measurement site was selected such that it was as far away as possible from potential sources of background noise (e.g. trees, occupied dwellings) and such that the noise environment at the site was typically controlled by wind turbine noise. In addition, only wind speeds where the noise level appears to be controlled by wind turbine noise have been considered. These wind speeds have been selected based on analysis of the measurement data and observations carried out on site during the measurements.

As an example, Figure 1 presents measurement results for Site B3, indicating a range of wind speeds where the measured noise level is controlled by turbine noise. This is evident due to the small spread of the measurement data when compared to wind speeds where the background noise level causes significant variation between measured levels at the same speed. At lower wind speeds, there are a number of measurements where the turbine clearly cut-out due to low wind speed during the measurement period. These have been excluded from further analysis.

The change in measured noise levels with wind speed correlated almost precisely with the change in sound power levels for the turbines, an indication that the noise levels were controlled by noise from the turbines. This is discussed in more detail in our other paper (Evans and Cooper, 2011).

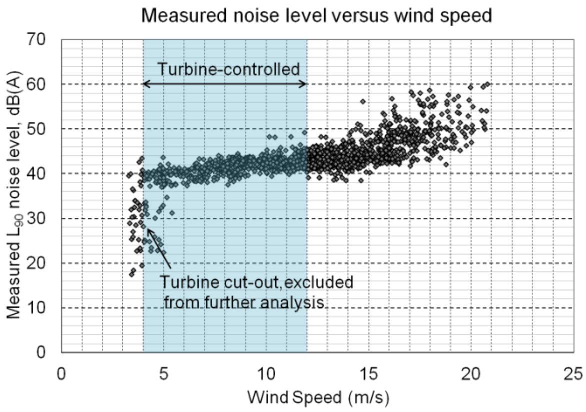


Figure 1. Example of measured noise levels versus wind speed with turbine-controlled wind speed range

RESULTS

The compliance noise level measured using the 2009 SA Guidelines was selected as a reference level, against which the results from all other compliance measurement methods were compared. The 2009 SA Guidelines use the worst case wind direction and the L_{A90} noise level, which is expected to make them less susceptible to variation than some other methods. The use of the downwind directions should, in practice, provide a more repeatable compliance measurement as the result will not be influenced by variations in the distribution of wind directions that occur during the compliance measurement period. Additionally, L_{A90} levels should be less susceptible than L_{Aeq} levels to the influence of short term extraneous noise.

In support of this supposition, compliance measurements were recently repeated at one of the sites in this study, almost two years after they were first assessed using the 2009 SA Guidelines. The variation in the measured compliance level was less than 1 dB(A) over the entire range of wind speeds where the noise level appeared to be turbine-controlled. This demonstrates the repeatability of the 2009 SA Guidelines compliance measurement method when used at locations not influenced by extraneous noise.

Table 2 summarises the average difference in compliance measurement results achieved between the tested methods at each site. The single value has been obtained by averaging the single 'measured' noise level at each integer wind speed over the range of wind speeds that appeared to be turbine noise controlled.

We note that Method 1 of the AS 4959:2010 for compliance assessment requires the measurement of L_{A90} levels, with a numerical adjustment applied to account for the likely difference between the L_{A90} and L_{Aeq} level. Our assessment is based on measured L_{Aeq} levels instead. As both the 2009 SA Guidelines and AS 4959:2010 have been applied assuming a downwind direction, comparison between the AS 4959:2010 and 2009 SA Guidelines results provides the difference between the measured L_{Aeq} and L_{A90} level.

No difference is provided between the 2009 SA Guidelines and NZS 6808:1998 for site D1 as L_{A95} levels were not measured at that site.

Table 2. Compliance level measured using the different compliance methods, relative to the 2009 SA Guidelines (dB(A)).

	Compliance measurement method		
Site	***NZS 6808:1998***	***NZS 6808:2010***	***AS 4959:2010***
A			
A1	-1.5	-1.1	+2.8
A2	-1.5	-1.0	+2.5
A3	-2.0	-1.5	+1.9
B			
B1	-1.0	-0.7	+1.7
B2	-0.7	-0.4	+1.2
B3	-1.1	-0.7	+1.5
C			
C1	-0.5	-0.2	+1.6
C2	-0.7	-0.4	+1.4
C3	-0.7	-0.4	+1.3
D			
D1	-	-0.3	+1.1
Mean Difference	**-1.1**	**-0.7**	**+1.7**
Standard Deviation	**0.6**	**0.4**	**0.5**

Table 2 indicates that the application of other wind farm standards used in Australia results in levels up to 2.0 dB(A) lower, and 2.8 dB(A) higher than respective results obtained through application of the 2009 SA Guidelines. However, as later discussed, the 2.8 dB(A) difference between the 2009 SA Guidelines and AS 4959:2010 results at site A1 is believed to be affected by extraneous noise.

Discussion of L_{A90} and L_{A95} results

It is observed that measurements undertaken using NZS 6808:1998 provide the lowest compliance levels, with a mean level 1.1 dB lower than the 2009 SA Guidelines and a range of results between 0.5 and 2.0 dB lower than the 2009 SA Guidelines. However, we note that this does not necessarily translate to a 0.5 to 2.0 dB less stringent end result at the residences. Existing background noise levels used to determine noise criteria would also be measured using the L_{A95} assuming that the NZS 6808:1998 method had been applied throughout the planning phase as well as during the compliance monitoring phase. Noise criteria determined based on the background L_{A95} + 5 dB approach would be more stringent than those determined using an L_{A90} level.

The variation in differences between noise levels measured under the 2009 SA Guidelines approach and NZS 6808:1998 approach was 1.5 dB (differences of between -2.0 and -0.5 dB). This result appears to be attributable to the combination of the difference in wind directions used for the assessments, turbine layout, and difference between the L_{A95} and L_{A90} levels. The difference in L_{A95} and L_{A90} is 0.3 to 0.5 dB, as provided by comparison of the NZS 6808:1998 and NZS 6808:2010 results in Table 2 (the only difference between these being the NZS 6808:2010 use of the L_{A90} rather than L_{A95}). The remaining variation in levels is attributable to different proportions of downwind measurements in the total measurement period, and layout of turbines on site.

Discussion of L_{Aeq} results

The AS 4959:2010 results provide the highest measured levels across all measurement sites. The comparison of the AS 4959:2010 and SA Guidelines methods provides the average difference between L_{A90} and L_{Aeq} levels across the measurement sites.

From site observations at the base of a turbine it might have been expected that locations close to turbines would experience greater differences between L_{A90} and L_{Aeq} levels, due to the blade passing of a single close turbine being more noticeable than the blade noise on a group of distant turbines. Figure 2 presents the difference between the measured L_{A90} and L_{Aeq} levels with distance.

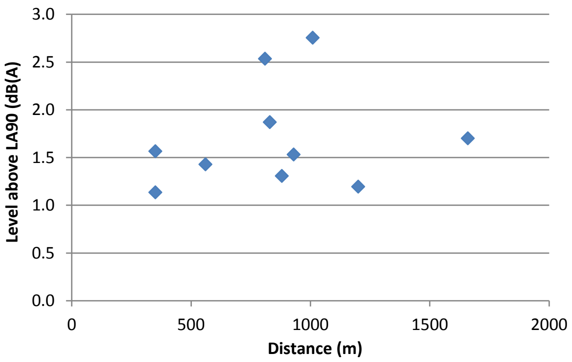


Figure 2. Level of L_{Aeq} above the L_{A90} with distance.

There is no observable trend in difference between the L_{A90} and L_{Aeq} results with distance over the measurement range of 350 to 1700m. Rather, the sites where both site observations and plots of noise level v's wind speed suggested greatest influence of ambient noise correspond to the sites with highest difference between the L_{A90} and L_{Aeq} levels.

While it is difficult to quantify the influence of ambient noise on the measurement sets it is believed that the L_{Aeq} results at sites A1, A2 A3 and probably B1 have been significantly altered by ambient noise. If the significant outliers A1, A2 and A3 are excluded from the data set the mean difference between L_{A90} and L_{Aeq} across the seven remaining sites is only 1.4 dB(A). This is less than the previously suggested correction of 1.5 to 2.5 dB(A) (ETSU, 1996). Our result suggests that L_{A90} levels should be increased by no more than the minimum required by AS 4959:2010, which is 1.5 dB(A).

It is possible that the difference between our findings and those reported in ETSU is the result of extraneous noise during the ETSU assessment, or measurements undertaken at very close distances to a single turbine where amplitude modulation may have been greater.

Finally, we note that the AS 4959:2010 Methodology 1 does not allow for the correction of L_{A90} compliance measurements for background noise, which the standard notes is a conservative approach. The lack of the ability to correct for the contribution of background noise when using this method will further increase the difference between the SA Guidelines and AS 4959:2010 results. There is potential for the inability to correct for background noise to be sufficient to incorrectly indicate non-compliance with criteria.

Comment on alternative measurement techniques

There are a number of alternative compliance measurement techniques proposed by the various standards including; attended on/off measurements, long term measurements at 'secondary locations' adjacent to residences, long term measurements at 'derived locations' between the turbine and residence with a correction applied for the predicted difference in noise level between the derived location and residence, and attended measurements at one residence to calibrate a noise model for the site.

Of all the alternative compliance measurement techniques proposed by the standards, the authors most prefer the use of measurements at a 'secondary location' which is a location selected where turbine noise levels are expected to be the same as at the residence but background noise levels are expected to be much lower.

In practice it is not always practical to place a noise logger in a 'secondary location' where the terrain and distance to all turbines match those at the receiver. Where it would be necessary to place a logger slightly closer or further from the turbines we suggest it is preferable to measure in that location and correct for the slight difference in noise level, rather than use attended measurements gathered over a limited range of conditions.

Our other paper (Evans and Cooper, 2011) demonstrates there is a consistent difference between the measured and ISO 9613-2 (G=0) modelled results at receivers scattered across different wind farm sites provided that the terrain between the turbines and receivers is consistent. We therefore also support the use of logging at a location slightly removed from a receiver i.e. in a 'derived location'. The correction applied for the difference in location should be determined using the ISO 9613-2 (G=0) prediction method, and the distance between the measurement location and residence should be always be minimised as far as is practical. If this method is used it is critical that significant differences in terrain between the derived measurement location and residence are avoided, based on our findings regarding influence of terrain on modelling results.

We believe that at sites where there is significant background noise the above two approaches are likely to provide a better indication of turbine noise than the primary compliance measurement methods currently used by the various Standards and Guidelines. The primary measurement methods involve taking measurements strongly influenced by background at receivers and then correcting them through subtraction of historical L_{A90} levels or alternatively measuring at the receiver and ignoring the presence of the significant extraneous noise.

The suitability of attended measurements for determining wind farm noise levels at an individual location has not been examined in this paper but we anticipate they would provide acceptable results provided that the sample size is sufficiently large. It may be simpler and less labour-intensive to take long term measurements at a secondary or derived location than it is to take a large number of attended measurements at a location influenced by background noise.

The alternative compliance technique provided by Methodology 2 of AS 4959:2010 uses attended noise measurements at one noise sensitive receiver to validate prediction model outputs and therefore compliance with criteria at the other receivers.

We have significant concerns regarding the suitability of Methodology 2 for checking compliance across a wind farm site. Using the receivers at Wind farm A as an example; sites A2 and A3 are at a very similar distance but on opposite sides of a small group of turbines. Predicted noise levels at the two sites were almost identical, but the terrain between the turbines and measurement sites varied greatly. The difference in terrain resulted in the difference in noise level measured between the two sites being 5.9 dB(A). If Methodology 2 had been applied using attended measurements at Site A2 the compliance level determined for Site A3 would have been almost 6 dB(A) too low. We therefore strongly suggest that the use of Methodology 2 should be avoided and this method in the Standard revised as soon as practical.

CONCLUSION

A comparison of the compliance results obtained from the various wind farm standards used in Australia has been undertaken. Noise measurements collected from 10 measurement sites around four different wind farms have been used during our assessment. Each measurement site selected for this analysis exhibited wind speeds where noise measurements were clearly controlled by wind turbine noise, with only data from those speeds assessed.

The compliance noise level measured using the 2009 SA Guidelines was selected as a reference level, against which the results from all other compliance measurement methods were compared. The measurement results obtained using the other wind farm standards are at levels up to 2.0 dB(A) lower, and 1.7 dB(A) higher than respective SA Guideline results at some measurement locations.

Application of NZS 6808:1998 results in the lowest measured compliance levels, with mean level 1.1 dB lower than the SA Guideline. This result is attributable to both the use of an L_{A95} descriptor rather than L_{A90}, and assessment over all wind directions rather than just downwind conditions. When compared to the NZS 6808:1998 standard, the new NZS 6808:2010 standard provides compliance results approximately 0.4 dB(A) higher.

AS 4959 provides the highest measured compliance results, with mean difference between the L_{A90} and L_{Aeq} found to be 1.4 dB when several outlier sites which were believed to have been influenced by extraneous noise are excluded.

This paper complements the findings of our paper titled 'Comparison of predicted and measured wind farm noise levels and implications for assessments of new wind farms' (Evans and Cooper, 2011), which is also presented at this conference. Together they can be used to compare the accuracy of a number of noise prediction methods to compliance results obtained from a variety of compliance measurement approaches.

Based on the findings of both papers some commentary is provided on the range of alternative compliance measurement methods used in Australia. The authors strongly suggest that Methodology 2 of AS 4959:2010 is revised as soon as is practical.

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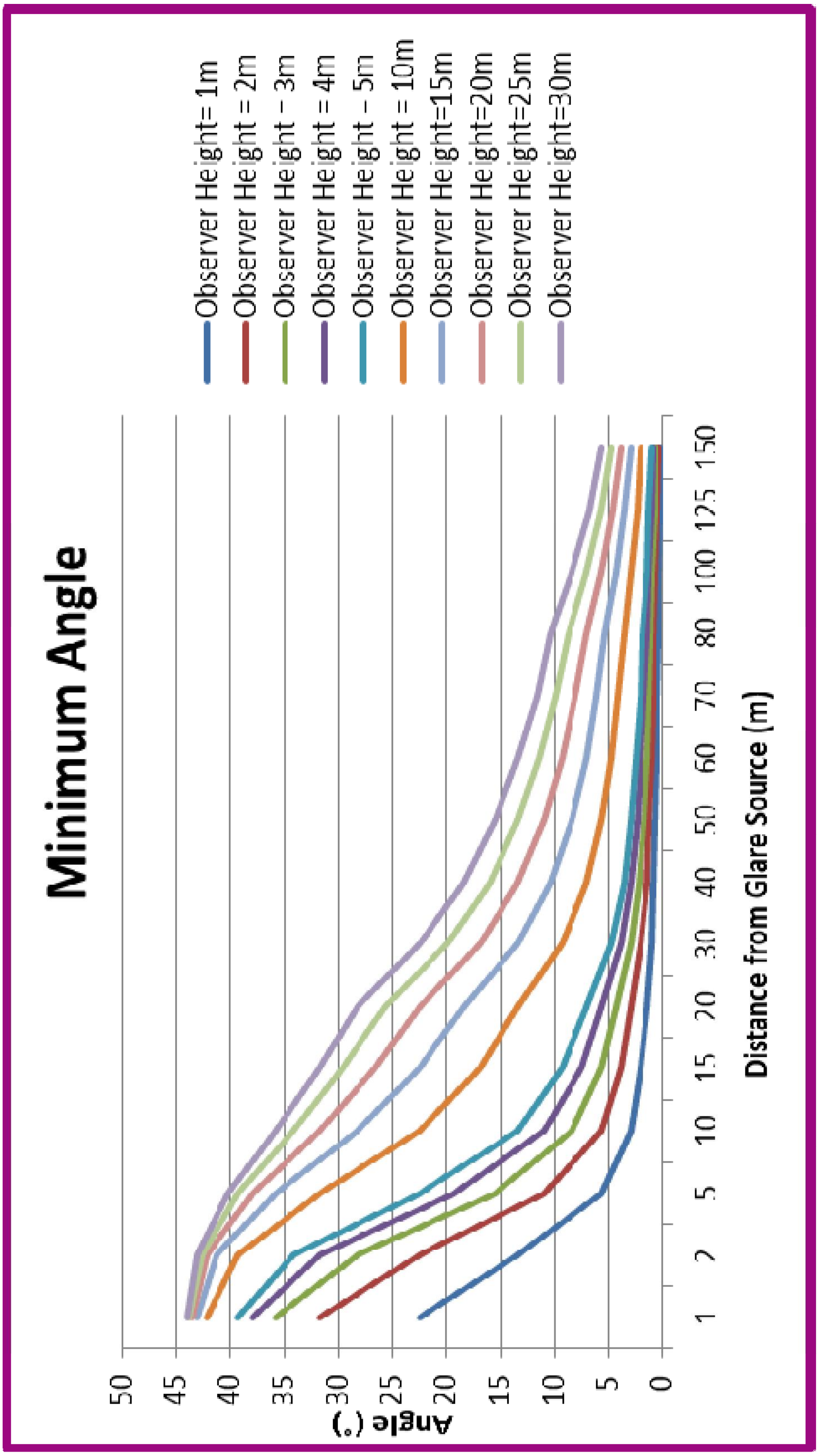
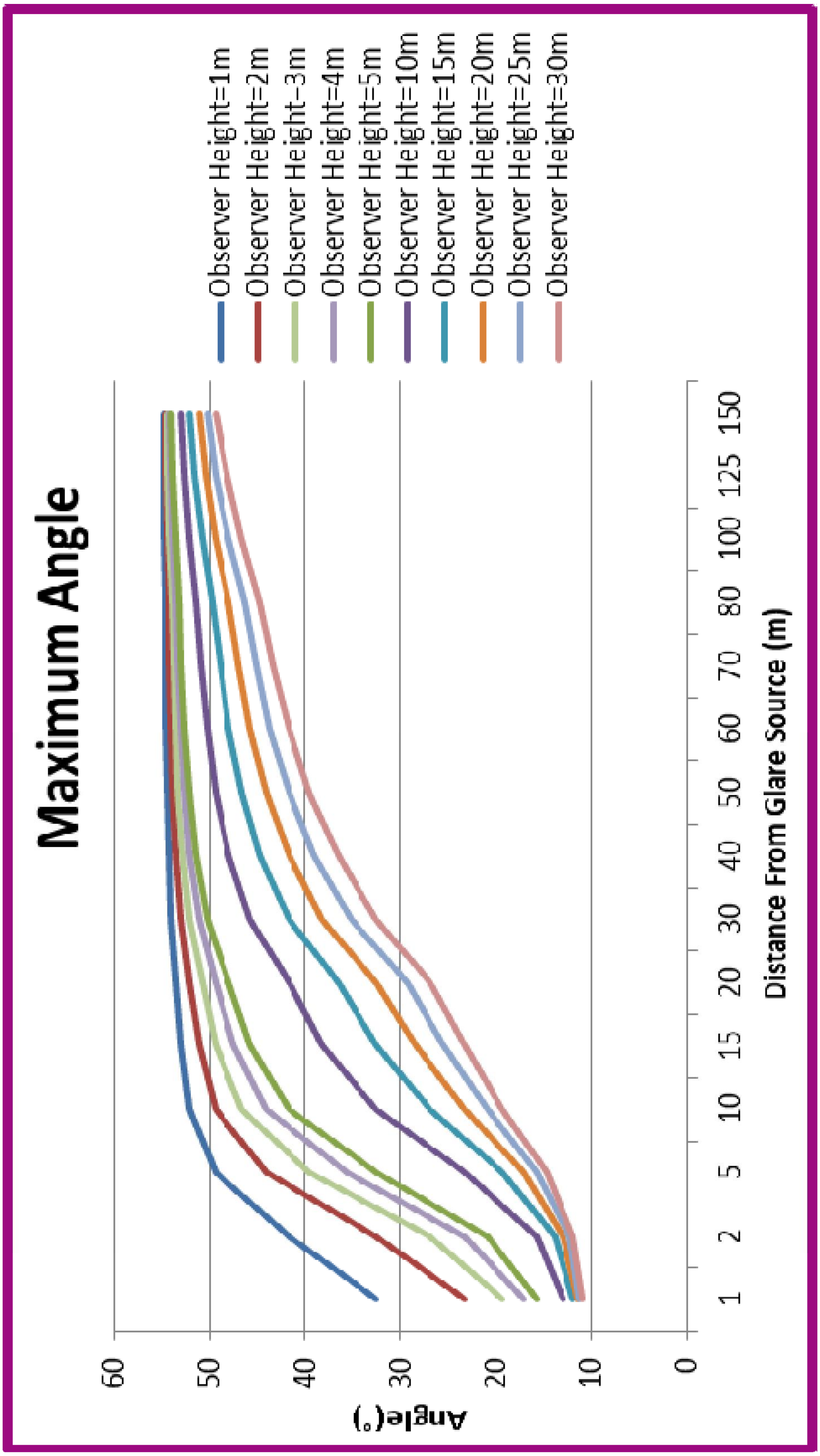
Appendix D

Solar Panel Critical Angle Graphs



Note: Observer height is relative to solar panel installation.



Note: Observer height is relative to solar panel installation.