ISSN 0113-8359

NEW ZEALAND ACOUSTICS

Volume 33, 2020, Issue #2

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Welcome to the second edition of *New Zealand Acoustics* for 2020.

With a difficult few weeks of lockdown behind us, and likely more challenges facing us all in the coming times ahead, we are hopeful to resume in one way or another more familiar work, social and recreational activities. Due to the current COVID-19 situation, we are diverting away from our normal format of Editors and President write-ups to bring a united message from the Council following the latest council meeting held in mid-April.

It is no secret that 2020 was planned to be a very big and exciting year for acoustics both in New Zealand and internationally. However, changes have had to be made.

With the evolving pandemic, and consideration of all circumstances including travel restrictions, it was with some sadness that the Organising Committee made the difficult decision to postpone 'Acoustics 2020'. However, the health and well-being of our members, delegates and sponsors has always been the highest priority, and to ensure that the conference is safe and successful for all parties involved.

The joint Australian and New Zealand conference will now take place from the 31st of October to 2nd of November in 2022 and has been rebranded to 'Acoustics 2022'. The conference will still be held at Te Papa in Wellington, where we look forward to hosting our Australian friends. Please sign-up at www.Acoustics2022.com to receive updates.

The Committee has recognised that the delay to the joint conference would result in a four year hiatus between conferences for ASNZ. An ASNZ conference in Auckland in early 2021 is proposed. We acknowledge this will be outside the typical rotation of cities, but we ultimately made this decision based on where most of our members and sponsors are located, and minimising travel. In consideration of the current economic market however, this conference will be a scaled-back event. The Committee is working to make this happen, so please stay tuned for further updates which will be posted on our website and LinkedIn page, and emailed to you.

You may have also seen other recent updates from our Secretary James Whitlock, including a recent message from Mike Stinson advising us that the International Year of Sound (IYS) celebrations have been extended into 2021. Check out www.sound2020.org for more information.

To keep up to date with all the news and events please visit the ASNZ webpage at www.acoustics.org.nz.

We wish you all good health and please keep safe. We know that during these unprecedented times there will be extra pressures and stress on you and your family. We encourage you all to be kind to each other and patient. Kindness and a smile cost nothing.

New Zealand Acoustical Society Committee Members – *Jon Styles (President), James Whitlock (Secretary), Siiri Wilkening (Treasurer), Lindsay Hannah, Tracy Hilliker, Tim Beresford Grant Emms, Mathew Legg, Neil Jepsen, Mike Kingan, Robbie Blakelock and George van Hout.*

New Zealand Acoustics is published by the Acoustical Society of New Zealand Inc
PO Box 1181, Shortland St
Auckland 1140
ISSN 0113-8359

Production by

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SPECIAL EDITION FEATURE

World Health Organization Guidelines on Community Noise 1999 to 2018: PART II NZ Perspective

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Purpose

The purpose of this paper is to provide an overview of the World Health Organization (WHO) guidelines for noise. It includes a review of the 1999 WHO Guidelines for Community Noise (GCN 1999), 2009 Night Noise Guidelines for Europe (NNGfE 2009) and the recently released Environmental Noise Guidelines for the European Region (ENGER 2018). The paper provides the reader with an overview of key areas of these WHO guidelines and related background research papers. This is the second (Part II) of two technical papers on the World Health Organization Guidelines for Community Noise to be published in New Zealand Acoustics. The first paper (Part I) was published in the previous issue (No 1, Vol 33, 2020).

New Zealand Context

Currently in New Zealand, there are eight acoustics standards for the measurement and assessment of environmental sound, including ones for specific situations, such as wind turbines, airports, heliports and roads. There are no New Zealand standards for rail noise, however agencies such as KiwiRail and the New Zealand Transport Agency (NZTA), do promote their own environmental noise standards for reverse sensitivity. There are no standards or guidelines in place for leisure noise. A list of the current New Zealand environmental noise standards is as follows:

- NZS 6801:2008 Acoustics – Measurement of Environmental Sound
- NZS 6802:2008 Acoustics – Environmental Noise
- NZS 6803:1999 Acoustics – Construction Noise
- NZS 6805:1992 Airport Noise Management and Land Use Planning
- NZS 6806:2010 Acoustics – Road Traffic Noise – New and Altered Roads
- NZS 6807:1994 Noise Management and Land Use Planning for Helicopter Landing Areas
- NZS 6808:2010 Acoustics – Wind Farm Noise
- NZS 6809:1999 Acoustics – Port Noise Management and Land Use Planning

The age of the standards ranges from the youngest at 10 years (NZS 6806:2010 and NZS 6808:2010) through to 28 years (NZS 6805:1992).

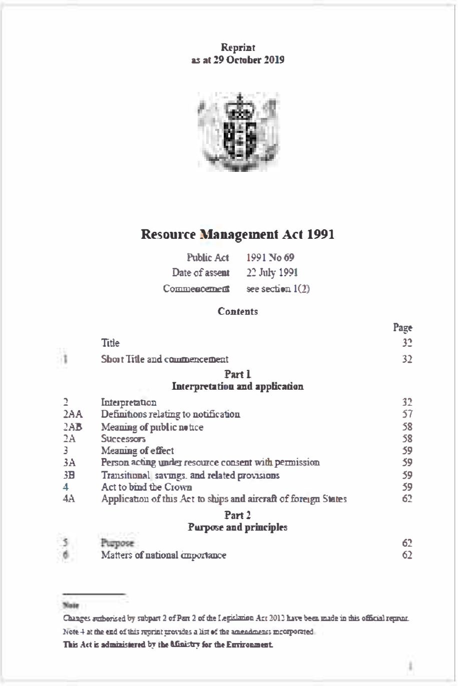
Reverse Sensitivity - A Uniquely New Zealand Perspective

Reverse sensitivity is the term used in the New Zealand planning system to describe the sensitivity of some activities to other lawfully established activities in the vicinity. Reverse sensitivity is the vulnerability of an established activity to objection from a new land use and typically arises where incompatible land uses are located in close proximity to each other, resulting in the potential for conflict and complaints from the more sensitive activity. Complaints and adverse reactions by residents can adversely affected the on-going viability of the legitimate activities. Many regional and district plans include provisions relating to reverse sensitivity. Noise setbacks or setting a required level of sound insulation for a noise sensitive space within a building or even an indoor sound level may be required in such provisions. Councils are often asked by the New Zealand road and rail authorities (New Zealand Transport Agency and KiwiRail) to include within District Plans land use planning measures to address noise and vibration effects to address what are termed 'reverse sensitivity' effects on the operation of the road or rail transport system.

Resource Management Act - New Zealand's Principal Environmental Legislation

New Zealand's primary environmental legislation which provides a framework for managing the effects of activities on the environment is the Resource Management Act 1991 (RMA 1991) and amendments to it such as the Resource Management Amendment Acts (1993 onwards). The RMA 1991 replaced many of the then existing regulations such as the Town and Country Planning Act 1977 and Noise Control Act 1982. The Noise Control Act states that the act shall be read together with and deemed part of the Health Act 1956.

To achieve its goals, the RMA 1991 provides the process of planning and mechanisms for controlling potential or actual effects on the environment, including noise and vibration. The RMA 1991 aims to *'promote the sustainable management of natural and physical resources'* through sustainable management which involves balancing the use of resources with the need to protect the environment and to provide for the needs of future generations. To attain this, the RMA 1991 sets up mechanisms to control among other things,



Reprint
as at 29 October 2019

Resource Management Act 1991

Public Act 1991 No 69
Date of assent 22 July 1991
Commencement see section 1(2)

Contents

Note
Changes authorised by subpart 2 of Part 2 of the Legislation Act 2012 have been made in this official reprint.
Note 4 at the end of this reprint provides a list of the amendments incorporated.
This Act is administered by the Ministry for the Environment.

1

noise effects. Territorial Authorities such as City, District or Regional Councils, are mandated under Section 31(d) of the RMA 1991 to have the primary function for managing the effects of land uses, including noise and vibration. The over-riding requirement under the RMA 1991 is for the noise producer to recognise the general duty to avoid *'unreasonable noise'.* Usually this entails both physical precautions and management-based methods. The specific level of control is set out in detail in Plans (district or regional for example) prepared by Councils which set noise limits, usually based on the NZS 68XX standards. However, the noise limits in plans vary across districts, are not always consistent in setting levels or use of noise descriptors, and often to reference to older versions of NZS 6801 and NZS 6802.

Comparison of GDG and New Zealand Standard Descriptors

Many different sound descriptors (metrics or indices) have been defined and the traditional standard unit of a sound pressure level descriptor is the decibel (dB). For example, the time-average, A-(frequency) weighted sound pressure level ($L_{Aeq(t)}$ dB) or the N% exceedance sound pressure level (L_{AN} dB). Some of the most commonly used descriptors for environmental sound within the NZS680X series of Standards are the L_{A90}, $L_{Aeq(t)}$, L_{AFmax}, and L_{dn}. Due to the age of the standards, L_{den} and L_{night} are not used, however components of L_{den} such as L_{day}, $L_{evening}$ and L_{night} indicators are described in NZS 6801:2008 and NZS 6802:2008.

NZS 6802:2008 adopted the assessment approach of ISO 1996-2:2007 'Acoustics – Description, assessment and measurement of environmental noise – Part 2: Determination of environmental noise levels'. The new (at the time), concept of a *"Rating Level"* was defined as a derived level used for comparison with a noise limit. The 'Rating Level' (L_R) is used to rank the potential subjective response to the sound environment. The 'Rating Level' process has three main steps. The first step in the process is to obtain the Rating Level from measured L_{Aeq} sound levels via the applicable 'simple' or 'detailed' method, outlined below. This provides a measure of the overall magnitude of the sound. The second step is to apply any applicable adjustments to the L_{Aeq}. NZS 6802:2008 contains adjustments to L_{Aeq} for features which are likely to affect the subjective acceptability of the sound. The third and final step is to compare the Rating Level to the permitted noise limit.

Guideline Limits for the Projection of Health and Amenity Value

The NZS 6802 series have since 1977 provided recommended criteria or noise limits for the protection of Health and Amenity. These recommended limits are provided as guideline residential upper noise limit values using L_{AFmax} and L_{Aeq} in the latest 2008 version of NZS 6802. The standard states the guidelines are generally acceptable noise limits and communities can make more or less stringent limits to suit their particular circumstances. The standard states such limits when adhered to provide *"reasonable"* protection of health and amenity. The 2008 version of the standard introduced an evening time frame with limits between the day and night limits if Local Authorities wished to incorporate such in their rules. NZS 6802:2008 sets out the recommended Guideline Residential Upper Noise Limits. A daytime level of 55 dB $L_{Aeq(15\ min)}$ is set while a night time level of 45 dB $L_{Aeq(15\ min)}$ and 75 dB L_{AFmax} is set for the protection of health and amenity.

NZS 6802:2008 and WHO Guidelines

NZS 6802:2008 was published after the WHO GCN 1999 but prior to NNGfE 2009 and ENGfER 2018. The limits recommended in NZS 6802:2008 are consistent with the guideline values for community noise in specific environments published in the GCN 1999, which states that during the daytime, few people are seriously annoyed by activities with levels below 55 dB $L_{Aeq(16h)}$. The night-time limit recommended should not exceed 45 dB $L_{Aeq(8h)}$ outside dwellings so that people can sleep with windows open for ventilation and achieve the desirable indoor 30 to 35 dB $L_{Aeq(8h)}$ level as a design level to protect against sleep disturbance. The GCN 1999 recommends various guidelines for specific environments. In the case of bedrooms, the critical effect is sleep disturbance, where guideline indoor limits are 30 dB $L_{Aeq(8\ h)}$ for continuous noise and 45 dB L_{AFmax} for single sound events. The GCN 1999 does however acknowledge that lower sound levels may be annoying, depending on the nature of the sound source.

To protect most people from being 'moderately annoyed' during the daytime, GCN 1999 recommends the outdoor sound level should not exceed 50 dB $L_{Aeq\ (16\ h)}$. The night-time sleep disturbance threshold set were re-examined by the WHO Regional Office for Europe in NNGfE 2009. In this document, *"Interim targets"* were defined to encourage countries to gradually reduce the percentage of the population exposed to levels above specified targets expressed as $L_{night,\ outside}$, but these values are yearly averages and should not be directly compared with $L_{Aeq(8\ h)}$ values. The NNGfE 2009 are considered by WHO to be an extension of the GCN 1999. WHO guidelines have always been used in New Zealand Standards as the basis for protection of health and amenity values for an 'average' person's sensitivity. But currently New Zealand does not use the newer L_{night} noise descriptor in its standards. Also, the current ENGfER 2018 are focused specifically on the four specific types of noise source (traffic, aircraft, rail, wind and leisure) as opposed to generic environmental noise which NZS 6802:2008 covers.

Airport Noise

Generally, airport hubs are located close to cities and their large populations with airports being surrounded by various land-based activities including noise sensitive sites. There must therefore be a balance struck between the operation of the airport as an important transportation hub and the people that live around them. The standard 'NZS 6805:1992 Airport Noise and Management and Land Use Planning' is used as a basis for both managing maximum (long term) noise from airports, while also providing guidance on land use planning controls to deal with effects of aircraft noise on noise sensitive activities establishing within noise affected areas surrounding airports

NZS 6805 does state that if an airport is operational at night (some airports are subject to night-time curfews on flights) then night-time operations should be considered. The standard also recognises individual aircraft noise events at night could potentially cause sleep disturbance effects if not adequately managed. Although the standard does recommend a day/night L_{dn} limit, the standard does not include a limit on individual events. Some District Plans have adopted a night-time sleep disturbance 95 dB L_{AE} contour. As with the L_{dn} contours, this generally means that the airport operator must manage single aircraft movements that do not exceed 95 dB $L_{Aeq,1s}$.

Part 1 of NZS 6805 is the main focus of this review and sets out airport noise management using the *'Airnoise Boundary'* concept. In order to plan the use of the areas around airports, the establishment of a buffer zone (a large distance) between the noise source (the aircraft) and noise sensitive sites, such as residential dwellings or other noise sensitive locations, would be the most obvious solution. However, because land near airports is generally already highly developed and rezoning this land in District Plans to exclude certain development is not always possible, such buffer zones are generally unrealistic and unachievable in many cases. Therefore, it is the case that for most existing airports, noise sensitive locations must be catered for, bringing a balance between the airport and surrounding environments.

Overall the standard is designed to provide guidance for making rules in District Plans and Designations and managing airport noise. Non-flight related noise is outside the scope of the standard, being subject to NZS 6802. NZS 6805:1992 promotes land use planning which uses the 'Air Noise Boundary' to set long term limits on total noise emitted by aircraft activities at airports. It is recommended in this Standard that the controls are implemented via District Plan policies and rules. Planning instruments are envisaged that provide for efficient aviation activity at the airport and the need to protect community health and welfare, consistent with the RMA 1991. The formal determination of airport planning involves the public process set out in the First Schedule of the RMA 1991.

NZS 6805:1992 utilises a system in which a limit is set for the average daily amount of aircraft noise exposure that is permitted in the vicinity of an airport, and only inside a fixed working area defined by the 'Airnoise Boundary' is the noise exposure allowed to be greater than this. In this working area there are supposed to be rules for compatible land use, and periodic aircraft noise monitoring at the 'Airnoise Boundary' to ensure that the noise exposure is kept within the prescribed limits. The standard states that in the planning steps the sound exposure predictions for the setting of contours should be based on an average day flight operations during the busiest three month (90 days) of the year. The standard states that the contour predictions should be based on minimum 10-year period (or long term projection) using the FAA (Federal Aviation Administration) Integrated Noise Model (or similar) and must take into account a number of things, including but not limited to, aircraft types (current and future), flight frequencies and seasonal effects among many other things.

The standard guidance is for land use planning measures to define areas of land in District Planning Maps which show areas which require special control provisions and these areas are different from noise controls applicable in other parts of the District Plan. It is understood that this Standard was the first national standard to introduce a linear noise descriptor (not in dB), 'sound exposure', measured in pascal-squared-seconds (*or pasques*). The standard defines the "night-weighted sound exposure" (E_n) descriptor as the key descriptor with approximate values provided for comparison purposes only, using the traditional L_{dn} descriptor in dB. The two control boundaries recommended in NZS 6805 are the 10 Pa^2s E_n (about 55 dB L_{dn}) contour (outer control boundary) and the 100 Pa^2s E_n (about 65 dB L_{dn}) contour (inner "Airnoise Boundary").

Certain land use planning rules have been developed in relation to these contours. The standard states that after considering the matters in the standard pertaining to incorporating the boundaries, the local authority should incorporate into its District Plan a map showing the projected exposure contours showing the Air Noise Boundary and Outer Control Boundary.

The recommendations of NZS 6805:1992 also include land use planning measures in areas around the airport affected by aircraft noise. NZS 6805:1992 recommends that noise sensitive uses (such as residential uses, schools and healthcare facilities) not be permitted in a District Plan on sites located within the 100 Pa²s E_n contour area but maybe permitted in a District Plan within the 10-100 Pa²s E_n (about 55 to 65 L_{dn}) area (Outer Control Boundary) so long as suitable methods such as acoustic insulation is incorporated within new buildings housing noise sensitive activities such as sleeping areas. The standard recommends for sound exposure E_n > 1000 Pa²s (about 70 dB L_{dn}), that consideration should be given to purchasing existing homes, or relocating residents, and rezoning the area to non-residential use only. Regarding sound exposure, E_n > 1000 Pa²s (above > 75 dB L_{dn}), the standard recommends that *"there is a high possibility of adverse health effects - Land shall not be used for residential or other noise sensitive uses"*. There are no aircraft noise recommendations applying to areas receiving less than 10 Pa²s E_n (about 55 dB L_{dn}).

The 'Airnoise Boundary' is a critical contour as it defines the total measured exposure to noise emitted by aircraft using the airport. According to NZS 6805:1992, the objective of the 'Airnoise Boundary' is *"avoiding, remedying or mitigating any adverse effects on the environment, including effects on community health and amenity values whilst recognising the need to operate an airport efficiently"*. Controls associated with the Air Noise Boundary are therefore intended to manage the effects of aircraft noise associated with the movement of aircraft to and from the airport while providing for the safe and efficient operation of the airport.

In regards to the management area, the standard states that the airport operator shall manage its operations so that the three (3) month (90 days) average 24-hour night weighted sound exposure does not exceed the limit or are outside the air noise boundary, this is where Parts 2 and 3 of the standard apply as the airport operator must therefore be able to site and specify the required air noise monitoring system on the air noise boundary.

The standard also includes information on airport noise management. The standard states that only the Civil Aviation Authority (CAA) of New Zealand noise abatement procedures may be considered when using the Standard. One such example applies at the Wellington International Airport where New Zealand Civil Aviation Rule Part 93 Subpart C specifies the noise abatement requirements for Wellington Airport. Appendix B of that document shows a map for Wellington Airport identifying the noise abatement area. CAA rules state that no aircraft shall be flown over this noise abatement area at an altitude lower than that required by Civil Aviation Rule Part 91 (generally 1000 ft AGL (Above Ground Level) for flight over a populous area) or 1500 ft, whichever is the higher.

Application of the standard throughout New Zealand has been relatively consistent through adherence to the advice in the standard, but rules about acoustic isolation vary. Ultimately it is anticipated that the former Building Industry Authority and Environmental Sound Project's([1]) outcome now under the building division of Building Group Ministry of Business Innovation and Employment and expressed through amendments to the Building Act and Building Code and its related documents, will standardise all acoustic isolation measures and related ventilation provisions. The same will probably apply to equivalent provisions in, Helicopter, Road traffic and port noise standards.

Purpose	For the control of airport noise. Establishes maximum acceptable levels of aircraft noise exposure around airport and aerodromes for the protection of community health and amenity, whilst recognising the requirement for the airport to operate effectively. For use by local or regional government to control airport noise. Establishes maximum acceptable levels on noise for the protection of community health.
Applications	Only noise resulting from aircraft operations shall be considered when determining sound exposure contours and the air noise boundary.
Restrictions	Sound from airport activities except from aircraft taxing and in-flight. Light aircraft flight and ground movements not at airports should be assessed using NZS 6802.
Noise Descriptors	• E - Sound Exposure (Pa²s) • E_n - Night-weighted Sound Exposure (Pa²s) • Se - Single Event Sound Exposure (Pa²s) • L_{AFmax} - Maximum Sound Level • L_{Aeq} - Equivalent continuous sound level • L_{AE} - Sound Exposure Level (SEL) • L_{dn} - Day Night Level (dB)
Service Age	Approx. 28 years

Table 23 – *NZS 6805:1992 Airport Noise Management and Land Use Planning*

Helicopter Landing Noise

'NZS 6807:1994 Noise Management and Land Use Planning for Helicopter Landing Areas' was produced to provide guidelines for controlling helicopter landing area noise in the context of the then newly enacted RMA 1991 and after a series of contested cases. The purpose is to assess noise from helicopter landing areas and the foreword specifically states that the assessment of noise from airports for fixed wing aircraft is included in NZS 6805. This is because of the distinctive character of helicopter noise and the nature of helicopter operations chiefly being able to depart or arrive on a vertical slope, enabling helicopters to be much closer in proximity to noise sensitive sites.

The daily sound exposure from flight operations for any landing site depends upon the sound contributed by each helicopter landing and take-off, the number of these movements per day, and time of day that movements occur. Noise from any movements taking place between 10.00 pm and 7.00 am the next day are automatically penalised in the L_{dn} calculation so

[1] *The 'Environmental Sound Project' started in 1998 to develop immission criteria where RMA 1991 requirements required habitable building spaces to meet acoustical criteria for RMA 1991 purposes. The project tracked parallel with the New Zealand Building Code Clause G6 'Airborne and Impact Sound' Working Group revising the original inter-tenancy noise controls in the Building Code. In 2000 the projects were combined into one smaller committee. The work under Building Institute Authority then continued with consultation in 2004 with the Building Code Clause G6* ***Airborne and Impact Sound Consultation.*** *It is understood that work continues at the time of writing (September 2013) under the Building Group Ministry of Business Innovation and Employment.*

Purpose	Details procedures for the measurement and assessment of noise from helicopter landing areas and recommends land use planning measures where necessary to mitigate the adverse effects of noise on land uses surrounding the helicopter landing area. Provides details for the measurement and assessment of noise from existing or proposed helicopter landing areas and recommends land use planning measures under the Resource Management Act 1991, where necessary. Only applies to helicopter landing areas used for ten or more flight movements in any month or where flight moves are likely to result in L_{AFmax} levels exceeding 70 dB at night-time or 90 dB day-time in any residential zone or rural dwelling notional boundary.
Applications	Only noise resulting from helicopter operations shall be considered. Considers the distinctive character of helicopter noise and the nature of operations from helicopter landing area.
Restrictions	Does not apply to emergency operations: 1. Auxiliary operations such as ground maintenance which are outside the scope of the standard (NZS 6802 shall be used to assess these noise sources); 2. Sound from airport activities except from aircraft taxiing and in-flight are within the scope of NZS 6802; 3. Light aircraft flight and ground movements not at airports should be assessed using NZS 6802.
Noise Descriptors	• E - Sound Exposure (Pa^2s) • E_n - Night-weighted Sound Exposure (Pa^2s) • Se - Single Event Sound Exposure (Pa^2s) • L_{AFmax} - Maximum Sound Level • L_{Aeq} - Equivalent continuous sound level • L_{AE} - Sound Exposure Level (SEL) • L_{dn} - Day Night Level (dB)
Service Age	Approx. 26 years

4. Table 24 – *NZS 6807:1994 Noise Management and Land Use Planning for Helicopter Landing Areas*

that one movement taking place during this noise-sensitive period is equivalent to the sound energy produced by 10 of these movements taking place during daytime. This is consistent with international practice where L_{dn} has been used to describe aircraft noise for more than 30 years.

The standard is not intended to apply to infrequently used helicopter landing areas or to emergency operations such as search and rescue including training. This provision is intended to recognise the vital role for society's benefit of helicopters as emergency vehicles. However, this exemption is not intended to apply to bases solely for emergency purposes. In mixed usage bases, noise during emergency flight operations has been regarded by the Courts as being excluded from sound exposure calculation and assessment.

The standard, is however, intended to apply to helicopter landing areas used for ten or more flight movement in any month or where flight movements are likely to result in a maximum sound level (L_{AFmax}) exceeding 70 dB at night time or 90 dB during day time in a residential zone or within the notional boundary of any rural dwelling. The L_{AFmax} noise descriptor provides for night-time sleep protection for these low usage landing areas.

The approach of NZS 6807:1994 is to assess helicopter noise on a 24-hour basis (using L_{dn}) with a separate consideration of the maximum levels due to any night-time operations (using L_{AFmax}). The standard allows for a relaxation of the limits by 5 dB where background sound levels (L_{A95} under this standard) exceed threshold levels set in the standard. Hence, if this criterion is met, a limit of 50 dB L_{dn} would be permitted to be relaxed by +5 dB and becomes 55 dB L_{dn}.

Comparison with WHO Guidelines

NZS 6805:1992 and NZS 6807:1994 were both published before the WHO 1999, 2009 and 2018 guidelines. The current ENGfER 2018 guidelines strongly recommends reducing noise levels produced by aircraft below 45 dB L_{den}, as aircraft noise above this level is associated with adverse health effects. This is 10 dB lower (a 10 times reduction in sound exposure) than is used in both New Zealand air noise standards. For night noise exposure, the GDG strongly recommends reducing noise levels produced by aircraft during night-time below 40 dB L_{night}, as night-time aircraft noise above this level is associated with adverse effects on sleep.

Road Traffic Noise

Transport noise and vibration can cause a range of impacts on people and communities from general interference with everyday activities to more significant effects such as sleep disturbance. Environmental noise due to road traffic is not specifically managed and monitored in New Zealand. As urban centres have grown, more and more residential development has become closely located to major road transport corridors. For new residential developments near high noise routes, controls are usually put in place in the district plan on the building design so that the noise levels in all habitable rooms are at the levels recommended in GCN 1999. While this provides mitigation while indoors, it does not address day-time noise while outside in areas around the dwelling, where there will be a significant loss of amenity and noise annoyance.

For major roads where road traffic noise has increased over time, existing residents currently have no legal standing to stop/manage traffic noise near their homes. However, if the road is a new or altered state highway, then it is covered by the Standard 'NZS 6806:2010 Acoustics – Road-traffic noise - New and altered roads'.

NZS 6806:2010 is a multifaceted document over 120 pages long and representative of a modern technical environmental acoustic standard. Persons using the standard are assumed to have a good understanding of the science of acoustics as well as a good understanding of RMA 1991 and other legal and policy context in terms of New Zealand Transport Strategy and land use planning. Importantly, its application is restricted to the assessments required to obtain planning approvals under the RMA 1991 for new or altered roads and does not deal with noise emitted by the existing roading network (which is responsible for most if not all noise effects caused by vehicles operating on public roads).

One of the interesting things about this standard is that it represents only one element in a programme developed by New Zealand Transport Agency (NZTA) for assessing noise and vibration from new or altered roads. For example, the Agency has a standalone document entitled *"Guide to assessing road-traffic noise using NZS 6806 for state highway asset improvement projects"*. There is also a web site developed by NZTA intended to provide a range of information and tools to help ensure that traffic noise is managed in an effective and efficient manner, and to assist with the adoption of the new road-traffic noise standard NZS 6806. That approach is fairly unique to this standard in the NZS 680X series.

NZS 6806 aims to *"control"* traffic noise from new and altered roads to reasonable limits by providing noise criteria to address the adverse effects of this noise on people. It provides consistent procedures and requirements to measure, predict, assess, and mitigate road traffic noise establishing reasonable criteria for road traffic noise, taking into account health issues associated with noise, the effects of noise on people and communities, and the potential benefits of new and altered roads to people and communities.

The Standard does not address noise from existing roads except in relation to situations where new or altered roading projects interact with existing roads. Noise criteria are set based on the adoption of the "Best Practicable Option" (BPO) which integrates the approach of the RMA 1991 with the cost benefit approach used by roading authorities such as NZTA to justify spending on noise mitigation measures. While this represents a flexible approach, it means that a set of noise mitigation measures achieving appropriate noise limits in one roading project may be found to be unsustainable when applied to another project that has a different layout and regime of affected sites. The basis of the cost-benefit procedures is set out in Appendix D of NZS 6806, which provides a basis for calculating the costs and benefits of mitigation for various engineering designs for projects across New Zealand.

One of the perceived *"weaknesses"* by some parties of the past guidelines such as the draft Transit Guidelines was *"rigid technical compliance noise limits"* hence mitigation and related design solutions were not always what could be described as good economic value, that is the cost benefit in some instances resulted in construction of substantial barriers for the sake of say 1 dB attenuation, which has no definable benefit. Past guidelines also were perceived as failing in some cases in terms of planning and urban design outcomes. For this reason, NZS 6806 does not set rigid technical compliance requirements for noise, but instead provides "Categories" referred to as A, B and C of noise criteria.

As part of the detailed assessment process, NZS 6806:2008 requires ambient sound levels in the existing environment to be measured at representative noise sensitive sites. The aim is to quantify, in acoustical terms, the existing noise environment at a location of interest, however such data has no bearing on what will ultimately be determined as the BPO for noise mitigation associated with any roading project. The BPO concept is used within the NZS 6806:2010 to identify the most efficient noise mitigation option.

Noise mitigation options are assessed under the standard and if practicable, the "Category A" criterion (Primary Free Field External Noise Criterion) should be achieved. Category A sets a design noise level of 64 dB $L_{Aeq(24h)}$ for an altered road or a new road with traffic volume > 75,000 AADT (Annual Average Daily Traffic) at Design Year'. For new roads with volume of 2000 to 75,000 AADT at Design Year, the "Category A" design noise level is 57 dB $L_{Aeq(24h)}$.

The standard states that if it is not practicable to meet the "Category A" criterion, then mitigation should be assessed against "Category B", however, if mitigation is still not practicable to comply with Categories A or B then the standard states that mitigation should be implemented to ensure the internal criterion in "Category C" is achieved. Separate criteria apply to "new roads" as opposed to "altered roads". Noise Criteria from NZS 6806:2010 requires assessment for the design year which is a point in time no less than 10 years but not more than 20 years after the opening of the new road, or alteration of an alter road is expected.

The standard requires assessment at "protected premises and facilities" (PPFs) which represent noise sensitive locations where road-traffic noise is assessed and for which noise mitigation measures may be required. NZS 6806 does not apply to PPFs in urban areas that are located more than 100 m from the edge of the closest traffic lane for the new or altered road, or PPFs in rural areas located more than 200 m from the edge of the closest traffic lane.

As a limited example, NZS 6806 lists Maraes, overnight medical care, teaching (and sleeping) in educational facilities, playgrounds that are part of educational facilities that are within 20 m of buildings used for teaching purposes as PPFs.

Residential activities are also listed in the definition of PPFs such buildings used for residential activities including (but not limited to) boarding establishments, homes for elderly persons; teaching spaces and so on. The standard also lists a number of situations which PPFs do NOT include, such as residential activities which have predominately other uses such as industrial premises, garage or ancillary buildings or premises not yet built other than those which have a Building Consent.

As recommended within NZS 6806:2010, PPF assessment locations are grouped geographically into "clusters" where the PPF assessment locations are located within 100 metres of each other. The reason is to ensure only the most cost-effective mitigation options are considered.

The relevance here is for example an isolated dwelling (not forming clusters) roadside barriers may be considered ineffective as structural mitigation assessed as per NZS 6806:2010. This is because the barriers or screens may for example fail to provide the required 5 dB of attenuation. The control of noise from individual vehicle movements is beyond the control of the standard but prescribed in the Land Transport Rules.

The standard also advises that noise assessment should be undertaken by suitably qualified and experienced persons. This is the standard's way of advising persons wishing to use the standard and apply it that the standard and its application is very technical in content and persons using the standard are assumed to have a thorough understanding of the science of acoustics, including measurement, assessment, monitoring and analysis of traffic and related topics covered under the standard.

Purpose	Recommends noise criteria to be applied to road traffic noise from new or altered road received at protected premises and facilities. Sets out procedures and requirements for the prediction, measurement, and assessment of road traffic noise for new and substantially altered state highways and local roads. Intended to be used primarily by Local Authorities and road controlling authorities and seeks to promote quicker and consistent decision-making nationally regarding the management of road traffic noise. Provides best practice guidance and advice on methods for mitigating reverse sensitivity situations and the environmental effects of noise exposure on nearby noise-sensitive activities. Where any project includes a mixture of new and upgraded existing roads the roading authority shall determine the relevant criteria to be applied to each section of the road for traffic noise mitigation.
Applications	New and altered roads of scale and state highways.
Restrictions	Generally, not recommended to apply to low volume roads. Lists 15 detailed restrictions, the following is a sample of several (not all) restrictions • Existing roads • New and altered roads predicted to carry less than 2000 AADT; • PPFs located in urban areas and located >100m from the edge of the road • PPFs located in rural areas and located >200m from the edge of the road • The control of noise generated by an individual vehicle; • Noise from the construction or maintenance of roads (refer to NZS *6803);* • Vehicle induced ground borne vibration; • Vehicle noise from land that is not road (refer to NZS 6802); • Development of noise sensitive activities which will or may give rise to reverse sensitivity effects; and • Private ways. • Premises other than PPFs

Noise Descriptors	• $L_{Aeq(24\ h)}$ – main descriptor, long-term over 24 hours • $L_{A10\ (18\ hour)}$ - 10% centile level based on L_{pAF} or short L_{Aeq} • $L_{Aeq,t}$ - time-average A-weighted sound pressure level • $D_{nTw} + C_{tr}$ – standardised level difference as defined in ISO 717-1 using A-weighted traffic noise spectrum
Service Age	Approx. 10 years

Table 25 – *NZS 6806:2010 Acoustics – Road-traffic Noise – New and altered Roads*

Comparison with WHO Guidelines

NZS 6806:2010 was published after the 1999 and 2009 WHO guidelines but prior to ENGfER 2018. The WHO environmental noise guideline values for outdoor living areas are 50 to 55 dB $L_{Aeq(16h)}$ for moderate and serious annoyance respectively. This guideline value is set at the level of lowest adverse health effect and is intended to address various sources of environmental noise including annoyance effects, speech intelligibility and communication interference, disturbance of information extraction, sleep disturbance and hearing impairment caused by various sources of environmental noise, including road traffic noise.

The 'Category A' criteria in NZS 6806:2010 for new roads with medium traffic volumes of between 2,000 and 75,000 AADT is set at 57 dB $L_{Aeq(24h)}$, while for roads with high traffic volumes it is 64 dB $L_{Aeq(24h)}$. Firstly, these limits use a different noise descriptor than the WHO guidelines and so direct comparison is difficult. Having said that, using the ENGfER 2018 long-term guideline values for road traffic noise values of 53 dB L_{den} and 45 dB L_{night}, with the standard 10 dB night penalty, an estimate of $L_{Aeq(24h)}$ was calculated as 49-50 dB. This is 7 dB lower than the 'Category A' medium traffic flow criteria in NZS 6806:2010 and 14 dB lower than the higher traffic flow criteria, representing a substantial difference in noise levels and potential health effects.

So why are the criteria levels in NZS 6806:2010 substantially higher than the ENGfER 2018 environmental noise criteria for road traffic noise outdoors? Health of people and communities is part of sustainable management enabled by the application of the RMA 1991. Introduction of noise criteria in this standard recognises the WHO concern about increase in traffic noise and that growth in urban environmental noise pollution is unsustainable, because it creates adverse effects on health. Increase in traffic noise also adversely affects future generations by degrading residential, social and learning environments, with corresponding economical losses. Based on this, we expect the noise criteria in NZS 6806:2010 have been selected to limit adverse effects of road traffic noise on people above a 'reasonable level and health criteria', recognising as does WHO, that the evaluation of control options must consider technical, financial, social, health, and environmental factors. Whereas the ENGfER 2018 long-term guideline values for road traffic noise values seek a much higher level of protection.

WHO calls for precautionary action in any environmental planning situation as traffic noise is a global health problem. Precautionary measures in this NZS 6806:2010 include emphasis on land use planning, and isolation of buildings from traffic noise sources.

In GCN 1999, guideline long-term noise value for industrial, commercial and traffic areas is 70 dB $L_{Aeq(24h)}$. This criterion is intended to prevent hearing loss due to long-term exposure at this level. The high traffic volume road criteria in NZS 6806:2010 is well below this level.

New Zealand Transport Agency (NZTA)

The New Zealand Transport Agency (Waka Kotahi) is a New Zealand Crown entity tasked among other things to administer the New Zealand state highway network. The NZTA has obligations under the RMA and the Land Transport Management Act to manage noise and vibration from the state highway network. There are no National Environmental Standards, or other *mandatory* regulations, prescribing how the Transport Agency must meet these obligations. The NZTA has therefore developed its own policies and (reverse sensitivity) guidelines for the protection of the roading network by avoiding inappropriate development near state highways. This means the NZTA, territorial authorities, landowners and developers must all assume some level of responsibility for managing reverse sensitivity effects. To address noise and vibration reverse sensitivity issues, the NZTA requests District Plan rules and resource consent conditions for new and altered Protected Premises and Facilities (PPFs) near state highways. These requirements generally require the building design to achieve appropriate internal sound levels through directly setting an internal design sound level (indoor noise level) for example a design sound level of 40 dB $L_{Aeq(24h)}$ for residential living and sleeping spaces (bedrooms).

External Sound Insulation

The New Zealand Building Code, Clause G6 - Airborne and impact sound (1995) is designed to prevent undue noise transmission in building elements between occupancies or common spaces in household units. The building elements that are common between occupancies are required to be constructed to prevent undue noise transmission from other occupancies or common spaces in household units. It requires a Sound Transmission Class (STC) for walls, floors and ceilings of no less than 55, and an Impact Insulation Class (IIC) for floors of no less than 55.

A proposed amendment to G6 has been underway since 2008 with the intention of introducing a new clause to G6, 'Protection from Noise' to replace the existing clause, 'Air and impact sound'. It was to include a new verification method, with a change in philosophy from the performance of the materials to the performance of the building. The proposal would provide greater protection to occupants of new household units, from a range of sources, including external noise, not just noise from abutted occupancies. There was to be a change in the descriptors from Transmission Loss (TL) to NR (Noise Rating) and from STC to R_w (lab rated sound reduction index) and $D_{nT,w}$ (on-site sound insulation performance). The expected overall improvement was 3 – 8 dB (James Whitlock, *Acoustics 101 - and the NZ Building Code,* NZAS 39th Annual Conference, July 2015). However, five years later after it was expected to be confirmed by MBIE (Ministry of Business, Innovation and Employment) and 12 years after the process was initially begun, there is still no sign of the revised clause. In the meantime, some Councils have set rules or resource consent conditions setting a minimum sound insulation design criterion for the façade of the building, in addition to setting internal sound levels for the protection of health and amenity. Such criteria as $D_{tr,2m,nTw}$ > X dB + C_{tr} or $D_{nT,w}$ + C_{tr} >Y dB, are used.

An example where $D_{nT,w}$ + C_{tr} criteria may be used include a new or altered dwelling adjacent a heliport where the dwelling is located within a noise control boundary. Sound insulation is the ability of the building's façade (floor, walls, ceiling, roof, windows, doors etc) to reduce sound transmission from outside to inside. The $D_{nT,w}$ rating can be defined as the 'standardised level difference' (outdoor to indoor). $D_{nT,w}$ is technically room-to-room not façade performance and thus assumptions must be made when undertaking assessment. In the case of assessing $D_{nT,w}$ many rules or plans refer to ISO standards. The spectrum adaptation term (C_{tr}) is generally used in connection with the $D_{nT,w}$ sound insulation rating. The spectrum adaptation term when used in connection with the $D_{nT,w}$ sound insulation rating places further emphasis on low frequency sounds. By adding the C_{tr} adaption term to a sound insulation rating ($D_{tr,2m,nTw}$ or $D_{nT,w}$), the total sound insulation rating is increased when compared to just adopting the $D_{nT,w}$ or $D_{tr,2m,nTw}$ ratings on their own. Applying the spectrum adaptation term along with the $D_{nT,w}$ sound insulation rating this can make a noteworthy difference to level (and cost) of construction required for sound insulation. In New Zealand the most commonly adopted façade insulation levels are $D_{nT,w}$ + C_{tr} > 30 dB or $D_{nT,w}$ + C_{tr} > 35 dB. The $D_{nT,w}$ criteria normally results in the habitable spaces within buildings requiring mechanical or forced ventilation so windows can be kept closed.

Wind Turbine Noise

In New Zealand there are currently in excess of 16 wind farms in operation with just under 500 wind turbine generators, producing a total energy capacity of just below 700 MW. They supply around 6% of New Zealand's annual electricity generation, which is about the same amount of electricity as 300,000 kiwi homes use in a year. In addition, there are plans proposed for over 15 more wind farms developments to be built.

The current New Zealand wind turbine acoustic standard is *'NZS 6808:2010 Acoustics – Wind Farm Noise'.* NZS 6808:2010 was prepared under the supervision of the P6808 Committee of the Standards Council, after its predecessor NZS 6808:1998 having first been considered for review in 2004, was subject of another review in 2007. A technical committee was formed in 2008 to conduct a full technical review and the result was the release of the current 2010 standard.

Wind farm development in New Zealand has been controversial at times, with numerous Resource Consent Applications that have been granted being appealed in the Environment Court. In some cases, Environment Court decisions have been appealed on 'points of law' in the High Court.

NZS 6808 was developed specifically for the measurement and assessment of sound from wind turbine generators and wind farms in New Zealand conditions. It provides details on prediction, measurement and assessment with the stated purpose being to aid both wind farm development and Local Authority planning procedures by providing a suitable method for the measurement and assessment of sound from wind turbine generators. The standard provides specific guidance on limits of acceptability for sound received at residential and noise sensitive locations emitted from both wind farms and single wind turbine generators.

The original 1998 version of the was partly based on work done in the United Kingdom by the Working Group on Noise from Wind Turbines, documented in the report entitled 'The assessment and rating of noise from wind farms", ETSU-R-97, 1996'([2]). However, there were differences between the New Zealand Standard and ETSU documents, such as ETSU had day and night limits while NZS 6808:1998 took the variable approach of background sound level +5 dB. The 1998 version of this standard was written prior to significant wind farm development in New Zealand. The basic methodology proved robust, but experience and research over the following decade since its introduction, brought to light numerous refinements and enhancements which were addressed in the revised 2010 version.

The terminology and format of the NZS 6808:2010 were updated in line with international standards and the 2008 editions of NZS 6801 and NZS 6802 which includes adopting L_{A90} in place of L_{A95} as a measure of background sound levels – referenced in NZS 6808:2010 as $L_{A90(10\,min)}$ for background and wind farm sound levels.

Although other standards reference NZS 6801 for the measurement of noise, it is important to note that it is not appropriate to apply all parts of NZS 6801 for the measurement of wind farm noise. NZS 6801 refers to a "meteorological window'" under which normal noise measurements should be conducted, however this is not suitable for measuring sound from wind turbine generator(s) because wind turbines operate in wind speeds typically from 5 m/s to 25 m/s with sound pressure levels changing as a function of wind speed.

[2] The ETSU working group was made up of independent experts being established by the Department of Trade and Industry of the United Kingdom Government (now the Department of Business Industry and Skills, UK Government)

NZS 6808 requires background sound levels be measured $L_{A90(10\ min)}$ at relevant receiving locations with noise level data being measured concurrently with wind speed and directions. Once background sound levels are measured at relevant receiving locations, a direct correlation of wind speed versus background sound level is made for each receiving location by using a regression curve which describes this relationship (taking account of day and night and different wind directions if required. This data is then used to derive the recommended 'design limits' such as 40 dB or 5 dB above the measured background sound level (the greater of the two). Once the known limits are set, they can then be compared to the predicted wind turbine (predicted as L_{Aeq}) or wind farm sound pressure level at the relevant receiving site from the wind turbine(s) to allow for a statement regarding compliance with the recommended limits to be made. NZS 6808 states that there is no need to consider noise sensitive locations outside the predicted 35 dB $L_{A90(10\ min)}$ wind farm sound level contour.

The 2010 version of the standard also includes a provision for a higher degree of protection of acoustic amenity in an area. The new limits are referred to as the 'High Amenity Area' noise limits. NZS 6808:1998 did not assess or comment on cumulative wind farm noise effects from one or more wind farms or a single wind farm installation completed over several stages, this is addressed in NZS 6808:2010 with the standard stating that all cumulative wind farm sound affecting any noise sensitive site shall be assessed.

Like PPFs in NZS 6806, NZS 6808:2010 provides details on 'noise sensitive locations'. In regard to NZS 6808, the location of a noise sensitive activity associated with a habitable space or education space in a building not on the wind farm site are listed under NZS 6808 including (but not limited to) any part of land zoned predominantly for residential use in a District Plan.

In some instances, holiday cabins and camping grounds might be considered as noise sensitive locations. Matters to be considered include whether it is an established activity with existing rights. The standard also states that residential buildings designed for permanent habitation on land zoned for predominantly rural or rural-residential use are not classified as commercial or industrial for the purposes of this Standard. The standard acknowledges that wind farm sound may be *audible* at times at noise sensitive locations; however, the Standard does not set limits that provide absolute protection for residents from audible wind farm sound.

Comparison to WHO Guidelines

NZS 6808:2010 was published after the GCN 1999 guidelines, about the same time as NNGfE 2009 and prior to ENGfER 2018. The ENGfER 2018 guidelines conditionally recommend that policy-makers implement suitable measures to reduce noise exposure from wind turbines in the population exposed to levels above the guideline values for average noise exposure being < 45 dB L_{den}. As this limit uses a different noise descriptor to NZS 6808:2010, direct comparison is not possible. However, assuming a 'design limit' of 45 dB $L_{Aeq(24h)}$, the calculated L_{den} would be 52 dB, which is 7 dB higher than the ENGfER 2018 guideline value.

No recommendation is made for average night noise exposure L_{night} of wind turbines as the guidelines state the quality of evidence of night-time exposure to wind turbine noise is too low to allow a recommendation.

Purpose	Provides suitable methods for the prediction, measurement and assessment of sound from wind turbines. Provides reasonable protection for the health and amenity and noise sensitive locations consistent with the RMA 1991.
Applications	Generally, applies to wind farms consisting of wind turbines with a swept rotor area greater than 200 m^2 (eg. individual blade lengths greater than approximately 8 m). Includes Wind Turbine Generators located on land or sea (both horizontal and vertical). A wind farm is described as a wind turbine or a group of wind turbines installed near one another and electrically interconnected to a common grid.
Restrictions	Does not cover: 1. Small wind turbines less than this size are covered under NZS 6801 and NZS 6802; 2. Sound from mechanical or electrical systems connected to wind turbines used for other purposes (such as pumping or milling); 3. Sound from on-site sources other than wind turbines (such as substation equipment or machinery used for construction, servicing and maintenance.
Noise Descriptors	• L_{Aeq} – Time-average A-weighted sound pressure level (dB) • $L_{A90(10\ min)}$ - Background Sound Level and wind farm sound levels (dB)
Service Age	Approx. 10 years

***Table 26** – NZS 6808:2010 Acoustics – The Assessment and Measurement of Sound from Wind Turbines*

Leisure Noise

The concept of leisure noise is not new in New Zealand. The joint Australasian standard series on occupational noise management (AS/NZS 1269:2005), considers 'non-occupational noise exposure' and states that *"People who have significant occupational noise exposure should be informed that noise exposures are culminative and it is in their interest to limit noise exposure…"*. In the context of this standard, leisure noise is non-occupational noise exposure. However, as the standard is focused purely on hearing protection in the workplace and not the wider adverse effects of excessive noise, the limits are consistent with those used internationally of 85 dB $L_{Aeq,8h}$ and 140 dB L_{Cpeak}. This is supported with a guidance value of 75 dB $L_{Aeq,8h}$ above which employees should be provided with information and training on noise awareness.

In New Zealand 'recreational noise' is synonymous with leisure noise, although this may not always include noise exposure from personal listening devices (PLDs), which in the younger population has become a significant source of noise exposure internationally.

The Accident Compensation Corporation (ACC) is the New Zealand Crown entity responsible for administering the country's no-fault accidental injury compensation scheme. The primary focus of ACC with respect to noise, has been in the workplace, reducing the incidence of Noise Induce Hearing Loss (NIHL) and helping compensate those with NIHL that can be proven to be caused by occupational exposure.

The Ministry of Health (MoH) on its website under 'environmental health', briefly covers noise and has created an education pamphlet titled *"Noise around the Home"* (HE1122). This pamphlet provides guidance on the early signs of hearing damage, how sound is measured (with example sound pressure levels for common sources around the home), and how to protect your families hearing at home. It also states that:

> *"Many teens and adults set their personal listening device's headphones/ear buds at volumes that can cause hearing damage. Typically, a person can tolerate about two hours of 91 dB (LAeq) per day before risking hearing loss."*

Both the MoH and the ACC has provided guidance values for hearing protection, referencing the continuous occupational noise limit of 85 dB $L_{Aeq,8h}$.

New Zealand adopted the ISO Standard for 'safety of toys', as AS/NZS ISO 8124.1:2013. The acoustic requirements of this standard are reasonable extensive, with exposure of close-to-the ear toys specified as not to exceed 65 dB L_{Aeq} and all other toys 85 dB L_{Aeq}. Peak sound pressure levels using C-(frequency) weighting are also specified; 95 dB L_{Cpeak} for close-to-the ear toys, 115 dB L_{Cpeak} for general toys and 125 dB L_{Cpeak} for those using percussive caps or other explosive action. This is supported with a note that if 115 dB L_{Cpeak} is exceeded, the potential for hearing loss should be drawn to the attention of the user.

Comparison to WHO Guidelines

Like the leisure noise recommended values in ENGfER 2018, the various guideline and standard values relating to recreational noise exposure in New Zealand are based around the international occupational noise limits, with some adaptation of the limits for noisy toys that are designed to be used close-to-the ear by children.

The 'non-occupational noise exposure' statement in (AS/NZS 1269:2005), explicitly acknowledges that noise exposures are culminative, and thus recreational and occupational noise exposure need to be considered together. Whereas elsewhere this is generally absent in the guidance on noise, much like it appears to be in the ENGfER 2018 recommended guideline exposure level of 70 dB $L_{Aeq,24h}$ yearly average from all leisure noise sources combined. If, for example, an adult was exposed at work to 85 dB $L_{Aeq,8h}$ for five days a week over a working year and in additional had a leisure noise exposure of 70 dB $L_{Aeq,24h}$ yearly, the effective total exposure is likely result in NIHL.

Railway Traffic Noise

KiwiRail Holdings Limited (kiwiRail) is a New Zealand state-owned enterprise responsible for rail operations in New Zealand. Noise emitted from trains (other than at a station or in yards) are specifically excluded from the excessive noise provisions of the RMA 1991 s.326(1)(c). Other exclusions include vehicles on a road or aircraft operating (during or immediately before or after flight). Unlike other transportation methods such as road and air, rail noise is not covered by any existing New Zealand standard. The issues relating to railways and train-based noise are generally for noise from reverse sensitivity issues such as new dwellings being located close to existing main trunk rail lines. KiwiRail undertakes similar procedures to NZTA in that they request District Plan rules and resource consent conditions for acoustic insulation for noise sensitive sites near railway corridors or railway lines be adopted. Commonly adopted criteria set by KiwiRail for reverse sensitivity often relate to setting indoor sound levels for example a design sound level of 35 dB $L_{Aeq(1h)}$ for bedrooms or 40 dB $L_{Aeq(1h)}$ for other habitable spaces.

Comparison to WHO Guidelines

Since New Zealand does not have an environmental acoustics standard for railway traffic noise, no direct comparisons can be made to the ENGfER 2018 recommended values. However, the commonly adopted criteria by KiwiRail for reverse sensitivity of a design sound level for bedrooms of 35 dB $L_{Aeq(1h)}$ or 40 dB $L_{Aeq(1h)}$ for other habitable spaces, which is in line with the general guidance for indoor noise levels.

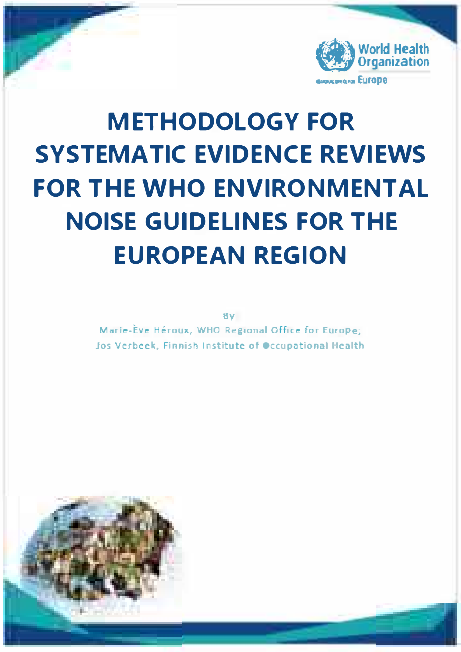
Additional WHO Guidelines and Research

Biological mechanisms related to cardiovascular and metabolic effects by environmental noise (2018)

The ENGfER 2018 focus on several non-auditory health outcomes, including sleep disturbances, annoyance, cardiovascular and metabolic diseases, adverse birth outcomes, cognitive impairment, mental health and well-being. This paper primarily deals with biological mechanisms related to cardiovascular and metabolic effects by environmental noise. It focuses on etiological pathways related to stress mechanisms and the role of effect modification by perceptual and psychological factors.

Methodology for systematic evidence reviews - WHO environmental guidelines for the European Region (2018)

Exposure to environmental noise has been demonstrated to have adverse effects on health. WHO has developed new environmental noise guidelines for the European Region, based on the latest scientific evidence retrieved and assessed using predefined systematic review methodology. This paper includes a description of the methodology used to conduct these systematic evidence reviews. It includes two protocols: one for the systematic review of health effects resulting from environmental noise and one for the systematic review of noise interventions.

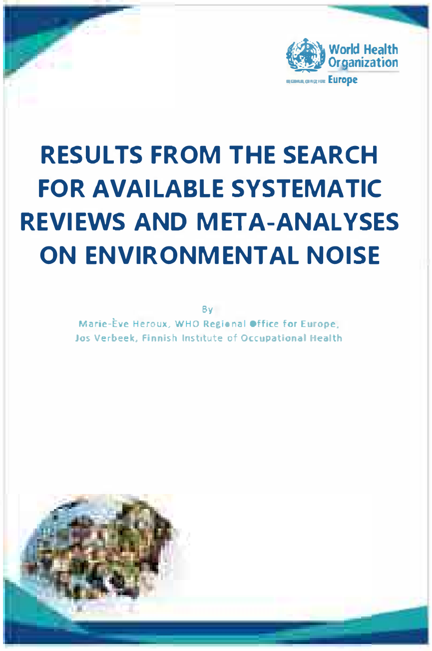

World Health Organization Europe

METHODOLOGY FOR SYSTEMATIC EVIDENCE REVIEWS FOR THE WHO ENVIRONMENTAL NOISE GUIDELINES FOR THE EUROPEAN REGION

By
Marie-Ève Héroux, WHO Regional Office for Europe;
Jos Verbeek, Finnish Institute of Occupational Health

Results from search for available systematic reviews and meta-analyses on environmental noise (2018)

In the context of the development of the WHO environmental noise guidelines for the European Region, this paper includes a description of the methodology used to search, select and assess the quality of available systematic reviews and meta-analyses on environmental noise. It presents the search strategies employed for the different databases and the list of included and excluded studies.

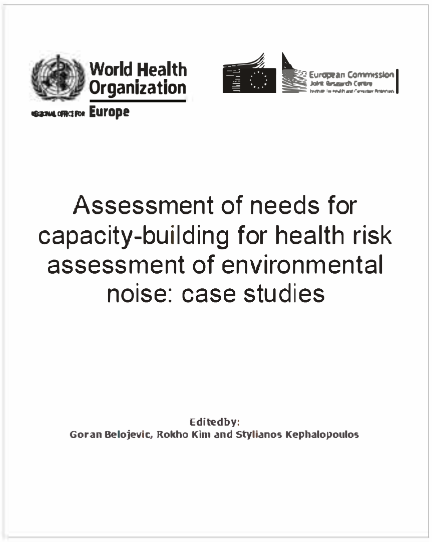

World Health Organization Europe

RESULTS FROM THE SEARCH FOR AVAILABLE SYSTEMATIC REVIEWS AND META-ANALYSES ON ENVIRONMENTAL NOISE

By
Marie-Ève Héroux, WHO Regional Office for Europe;
Jos Verbeek, Finnish Institute of Occupational Health

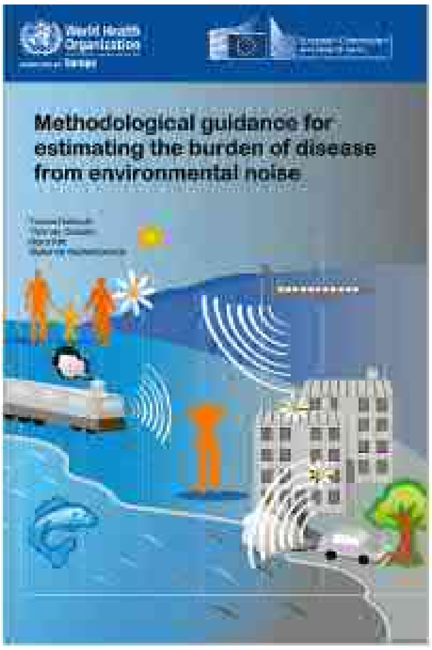
Assessment of needs for capacity-building for health risk assessment of environmental noise: Case studies (2012)

A group of international experts met in Bonn in October 2010 to define and agree on the assessment of the burden of disease from environmental noise, with a focus on cardiovascular disorders and sleep disturbance, and to promote knowledge transfer and capacity-building in European countries in the area of health risk assessment of environmental noise. The needs for awareness-raising and capacity-building in new EU member states, south-eastern European countries and newly independent states were studied on the basis of reports of experts from Albania, Belarus, the Czech Republic, Georgia, Serbia, Slovakia, Slovenia and the former Yugoslav Republic of Macedonia. The following common needs were identified: harmonization of the implementation of the Environmental Noise Directive 2002/49/EC, especially for strategic noise mapping and noise action plans, human resources development through education and training in health risk assessment, and provision of methodological guidelines for health risk assessment of environmental noise exposure. WHO, the European Commission and expert networks are important in promoting the transfer of knowledge and building human and institutional capacities for environmental noise risk assessment.



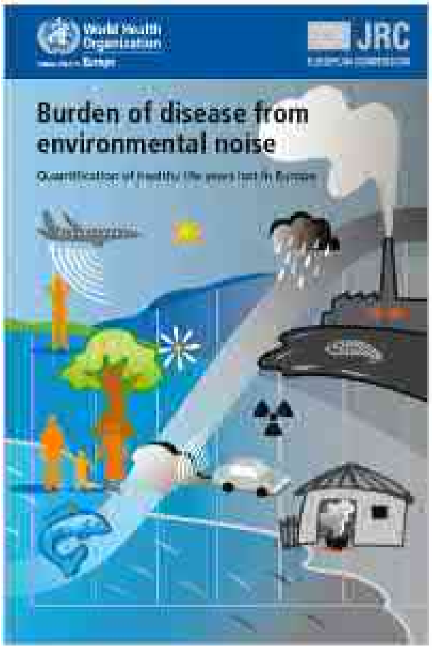
Methodological guidance for estimating the burden of disease from environmental noise (2012)

The World Health Organization, supported by the European Commission's Joint Research Centre, is issuing this technical document as guidance for national and local authorities in risk assessment and environmental health planning related to environmental noise. The principles of quantitative assessment of the burden of disease from environmental noise, the status of implementation of the European Noise Directive, and lessons from the project on Environmental Burden of Disease in the European countries (EBoDE) are summarized, together with a review of evidence on exposure response relationships between noise and cardiovascular diseases. Step-by-step guidance is presented on how to calculate the burden of cardiovascular diseases and sleep disturbance. The limitations and uncertainties of estimating disability-adjusted life years and the usefulness and limitations of noise map data are discussed.



Burden of disease from environmental noise. Quantification of healthy life years lost in Europe (2009)

The health impacts of environmental noise are a growing concern. At least one million healthy life years are lost every year from traffic-related noise in the western part of Europe. This publication summarizes the evidence on the relationship between environmental noise and health effects, including cardiovascular disease, cognitive impairment, sleep disturbance, tinnitus, and annoyance. For each one, the environmental burden of disease methodology, based on exposure–response relationship, exposure distribution, background prevalence of disease and disability weights of the outcome, is applied to calculate the burden of disease in terms of disability-adjusted life-years. Data are still lacking for the rest of the WHO European Region. This publication provides policy-makers and their advisers with technical support in their quantitative risk assessment of environmental noise. International, national and local authorities can use the procedure for estimating burdens presented here to prioritize and plan environmental and public health policies.



Environmental burden of disease associated with inadequate housing (2011)

A method guide, to the quantification of health effects of selected housing risks in the WHO European Region. Summary report: This summary report presents key findings of the report "Environmental burden of disease associated with inadequate housing". It provides evidence that the health consequences of inadequate housing are substantial. Improving housing in a way that removes or minimizes the negative impact on health and safety and promotes a healthier living environment is good for the residents and beneficial for society. Reducing the burden of responding to the demands on the health system attributable to inadequate housing is an obvious public health priority, but also something that makes economic sense. The findings set out in the full report provide ample justification for the principle that health should be at the centre of housing policy. Making housing healthy, affordable and sustainable should be a prime objective of all professionals and policy-makers involved in any aspect of housing and of health. This summary and its sister publication provide the evidence they need to make it so.

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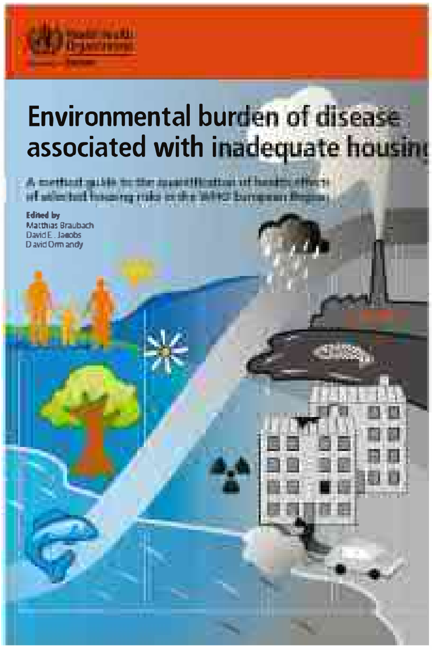

Publications and Reference Documents

The review is based on information available from World Health Organization web site: www.euro.who.int/en/health-topics/environment-and-health/noise

Qualifications and Copyright

This paper review is intended as a guide only; it is not intended to be surrogate for any expert advice from a professional acoustic consultant. The authors wish to make it clear that the contents of the paper have been sourced from a number of key sources including the World Health Organization (WHO) guidelines for noise and the New Zealand Acoustic Standards.

The reader and users should further understand that the information within this review does not attempt to cover all areas and applications of the standards and therefore there are a host of omissions. While all care has been taken in the preparation of this work and the information which is included is believed to be correct at the time of preparation, users of this paper should apply discretion and rely on their own judgments regarding the use of the above information.

Abbreviations

%HA – Percentage of the population 'highly annoyed'

AADT – Annual Average Daily Traffic

ACC – Accident Compensation Corporation

AGL – Above Ground Level

CAA – Civil Aviation Authority of New Zealand

EC – European Commission

EEA – European Environment Agency

END – 'The European Noise Directive' 2002/49/EC

ENGfER 2018 – WHO Environmental Noise Guidelines for the European Region 2018

ERF – Exposure–response function

EU – European Union

GRADE – Grading of Recommendations Assessment Development and Evaluation

GCN 1999 – WHO Guidelines for Community Noise 1999

GDG – Guidelines Development Group

ICBEN – International Commission on Biological Effects of Noise

IHD – Ischaemic Heart Disease

MoH – Ministry of Health

NIHL – Noise Induce Hearing Loss

NNGfE 2009 – Night Noise Guidelines for Europe 2009

NZTA – The New Zealand Transport Agency

PECCOS – Population, exposure, comparator, confounder, outcome and study [framework]

PICOS – Population, intervention, comparator, outcome and study [framework]

PLD – personal listening device

PPFs – Protected premises and facilities

RMA 1991 – Resource Management Act 1991

UNDG – United Nations Development Group

WHA – World Health Assembly

WHO – World Health Organization

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Clause G6 Airborne and impact sound (1995) of the New Zealand Building Code

Structural Insulated Panels (SIP) and Rain Noise

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Abstract

In this paper we discuss the requirements of the generic international standard (ISO, BS EN ISO 10140) for measurement of sound transmission through sample roofs exposed to simulated rainfall and of lessons learned during a recent test program. The test data forms the basis for calculating in-situ sound levels in rooms beneath the roof and we discuss the differences in sound produced by simulated rain to that of natural rain. The differences in impact velocity and raindrop distribution between simulated and natural rain are key factors that are not addressed by the Standard. In addition, an optional normalization test using a pane of glass is included, for the explicit comparison of products tested and as quality control for test laboratories, and its results have been incorrectly shown in some manufacturer's publicity material as the basis for calculating room sound levels. The Standard does not specify whether the normalization test should be carried out as a skylight or as glazing but the two tests have different requirements. Being optional and intended for inter-lab comparison suggests that the normalization data should not be released to clients as it is misleading and thus should be excluded from reporting.

Keywords: rain noise, roof systems

Introduction

Depending upon the listener's contextual situation, noise generated by rainfall can be soothing or annoying. Lengthy *YouTube videos* and *mp3* audio are available [1] for playing rain noise to support relaxation, yet in other circumstances the same sound masks communications and becomes a nuisance. It is in this latter context that we report on the incidence of rainfall on metal roofs supported by structural insulated panels (SIPs) – these panels are composites consisting of stiff facing panels adhered to a soft core, usually foamed expanded polystyrene or polyurethane. The intrinsic mass and acoustic insulation properties of the panels are low, which may lead to high levels of rain induced noise in the building's interior spaces. The spaces in question could be classrooms or open learning areas where good conditions for communication for teaching are paramount.

Figure 1 shows the typical form of response curve for the sound transmission loss characteristic of foam cored SIPs. The dips at frequencies around 630 Hz and 3150 Hz control the STC (Sound Transmission Loss) rating for the panel.

The response in the range of 630 Hz is a bounce mode of the masses of the facing panels on the springy foam core. Additional mass layers, to improve the transmission loss rating (as in the broken line curve in ***Figure 1***), stiffens the panel yet the upper and lower modal frequencies remain unchanged. The effect on the NC (Noise Criterion) rating, as determined for a room where SIPs are used in a roofing application, can be seen in ***Figure 2.***

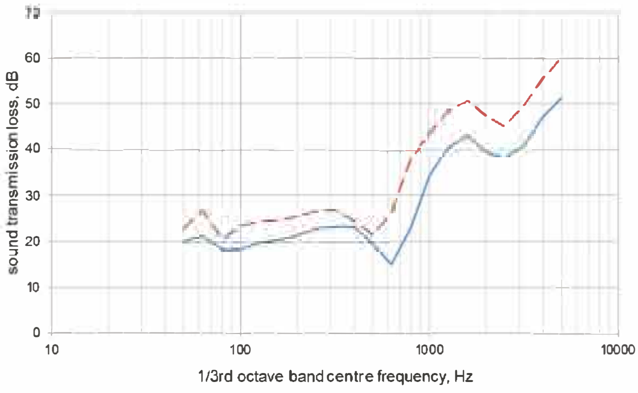

Figure 1 – Typical sound transmission loss response for SIPs

Clearly, the resonance mode in the 630 Hz region is limiting the rating for the room. The broken line curve represents a SIP with additional face treatments and the full line curve is the effect of adding insulation (with a suspended ceiling).

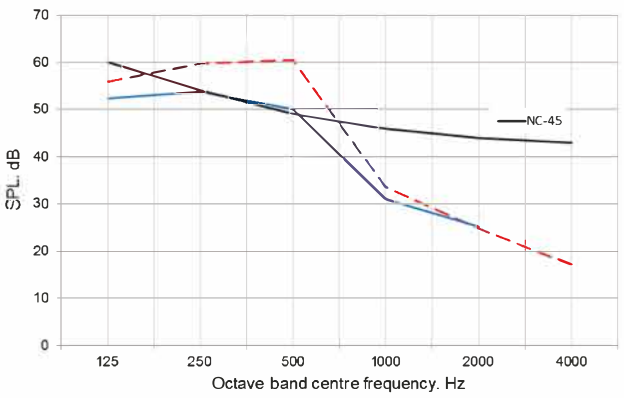

Figure 2 – Sound level in a room bounded by SIPs exposed to rain noise

Rain

Rain is a form of impact loading, generating noise by the excitation of vibration of roof panels by the dynamic force exerted by the falling droplets. The size of raindrops varies in natural rain and is related to the intensity or rainfall rate. Rain is classified as light, moderate, heavy or intense. In the laboratory, simulated rain as defined in Standards is classified as moderate, intense, heavy or cloudburst, and is generated in the laboratory as a means to make observations under reproducible and standard conditions. It does not correlate well with natural rain but the spectral character of the noise is consistent, whilst the sound level is at variance. The impacting raindrops excite the natural modes of vibration of the exposed roof panel and the resulting motion is radiated as sound. The modal frequencies of the roof structure are determined by the mass, boundary conditions (screw or nail fixing and their spacing), the spacing and material of the purlins, and system damping (overlap joints, membranes, material). For a given installation then, as would be expected, an increase in rainfall rate leads to higher noise being generated. Lower frequency modes require higher input energy to excite and so may not be present in low intensity rain.

Design

For acoustic design and evaluation purposes, international standards [2] use 'heavy' rainfall for simulated testing. This is defined as rainfall up to 40mm/h. This rate may or may not be suitable for designs for specific locations and results would need to be tailored accordingly. For Greymouth and Auckland in New Zealand for example, the average rainfall rates sourced from NIWA and the NZ MetService, as found on https://www.weather-atlas.com/en/new-zealand/auckland-climate, are as shown in *Figure 3*.

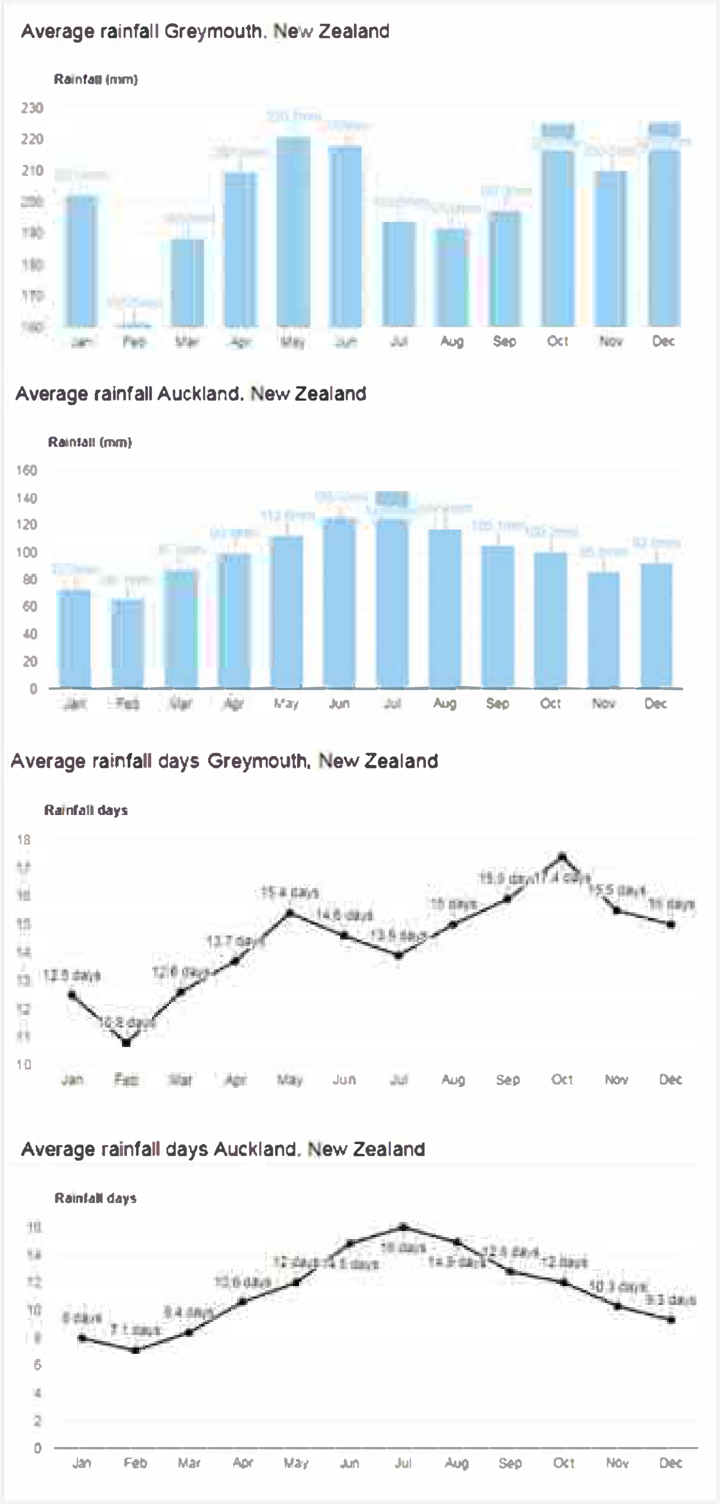

Figure 3 – Rainfall data for two sites in New Zealand [data from NIWA and NZ MetService via weather-atlas.com]

Auckland has 60 to 140 mm of rain in a month, falling over 8 to 16 days. Greymouth has 160 to 260 mm of rain per month, falling over 10 to 16 days; On average, Greymouth receives twice as much rain annually than Auckland – but neither record says anything about intensity of rainfall, or how often one can expect a rainfall rate of 40 mm/h and for how long it may last. In New Zealand, the Ministry of Education design guidance document [4] specifies a sound level performance of NC 45 or less as the rain noise criterion for all open learning spaces, irrespective of rainfall rate. Thus, for areas of high rainfall, such as Greymouth, the solutions for the roofing system will be more onerous than for an area with lower or much lower rainfall. In the UK, the comparable education sector document [5] specifies background noise levels to be achieved in various rooms of a school and these must not rise by more than 25 dB as a result of the contribution from rainfall. The document also differentiates between new buildings and refurbished ones and the difference mostly amounts to – 5 dB, i.e. indicative of a trend to improved (higher standard) acoustic environments. Taking the open learning spaces as an example, [5] specifies an upper limit of $L_{Aeq,30mins}$ 40 dB (new builds) and 45 dB (refurbished buildings). This then gives rain noise limits of 65 and 70 dB respectively. In comparison, the New Zealand document [4] specifies NC45, and taking the octave band values for that criterion between 125 Hz to 8000 Hz, this equates to 51.3 dB – substantially lower than the UK case but a lot higher than the specification for ambient background, L_{Aeq} 30 to 45 dB, depending upon the use definition of the space. The challenge is to determine the make-up of the roof system to ensure that these noise criteria are met for a given design rainfall rate and recognising that European case studies will be different than for application in New Zealand.

Some rainfall rate guides are available, such as shown in ***Figure 4*** for the Waitakere district of Auckland, and these are mainly used for prediction of flooding and sizing of drains and guttering. An interactive high intensity rainfall prediction tool is available at NIWA: https://www.niwa.co.nz/information-services/hirds.

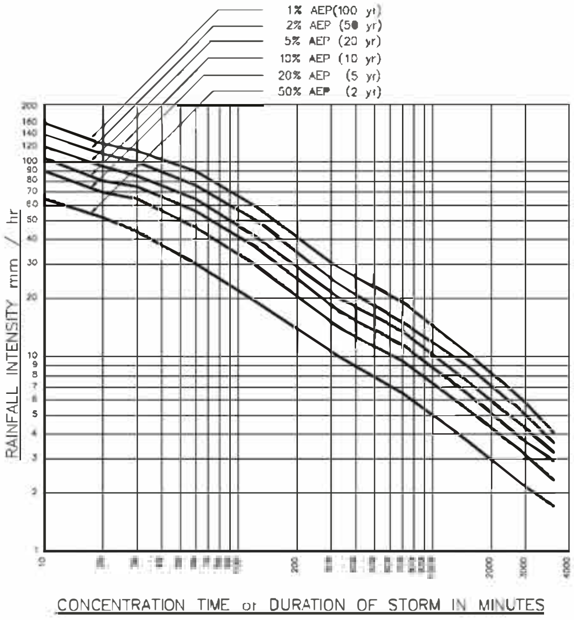

***Figure 4** – Waitakere Council Engineering Standards graph for rainfall intensity*

(Plotted from NZ MetService data 2002 for Whenuapai)

These tools include a temporal component that is not present in the design guides [4], although [5] does use the $L_{Aeq,30mins}$ metric. ***Figure 4*** indicates that there is a high probability that there will be at least one event in two years where rain with an intensity of 40 mm/h will fall for 30 minutes duration – in Auckland. Considering that the rain event would have to fall during a normal school day and that there are only 190 school days in a year, the probability of being in a classroom during the event is quite low – but never-the-less we are required to design for it.

Predicting Rain Noise Levels

Three methodologies are in use:

4. Use test data for the specified roof profile to determine the noise level generated and then use airborne sound transmission loss data to estimate the attenuation through the constructed roof system and into the room below.

5. Use data for a similar roofing system, making adjustments deemed necessary to account for the differences in the structure.

6. Use empirical formulations to estimate the rain noise received in the room below.

The prediction of expected noise levels from rainfall appears to be a "black art". It is based on many assumptions and cannot be viewed as sufficiently accurate as to be able to state with any certainty that any given roof/ceiling structure will meet a specified criterion [6]. The possible exception is where a roof structure has been tested and data is available to support calculation of an in-situ case. Even so, one has to make assumptions about the in situ case regarding flanking noise, room absorption, deviations in construction methodology for installing the sample compared with the real world, and the differences between test conditions using simulated rainfall and natural rain for the building site being considered.

The international test standard for testing roof systems for rain noise requires a sample size between 10 m² and 20 m² and the transmitted sound is reported as sound intensity in dB re 10^{-12} W/m². The sound intensity may be determined from the measurement of sound pressure levels within the test room below the roof sample or by measuring it directly using a sound intensity probe. The sound power developed by the roof system is determined by the product of the sound intensity and the area of the test sample. Once the sound power is known it can be used to find the sound intensity for an in-situ case by taking the quotient using the in-situ space's ceiling area. The calculations are carried out for each of the one-third octave bands between 100 Hz and 5000 Hz [7].

Testing

Simulated rain is different from natural rain as it seeks to standardise a testing method. Simulated rain must comprise 50% of the volume flow of droplets of the same size and have a specified impact velocity where in natural rain the drop size distribution is related to rainfall rate and therefore each event will have a different impact velocity distribution [8].

Rain noise testing is carried out to the international standard BS EN 10140-Part 1, Appendix-K. Parts 3 and 5 of the older version of the standard (ISO 10140) are referenced in the test methodology, and details of the drip tray for generating water droplets is detailed in Amendment 1 to Part 5 [9]. This amendment includes a table where the hole size and number of holes per unit area is given, but surprisingly there is no detail on hole entry and exit conditions. The holes are 1 mm diameter so small enough for surface tension to play a significant role in drop formation and capillary flow.

The Standard states a preference for randomly distributed holes yet the diagram associated with the text - Figure H.1 as shown in ***Figure 5***, does not show random holes. An example of a random pattern is shown in ***Figure 6***.

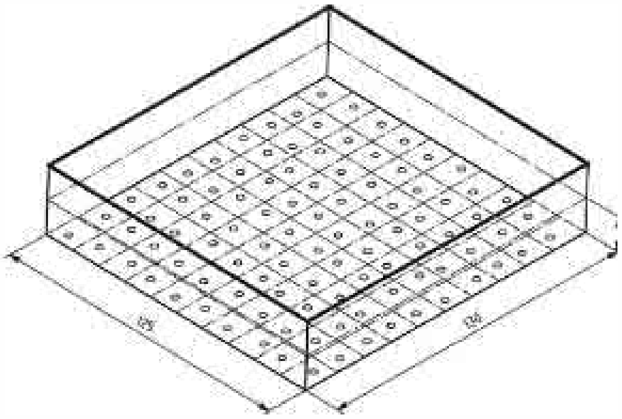

Figure 5 – Schematic Figure H.1 from [8]

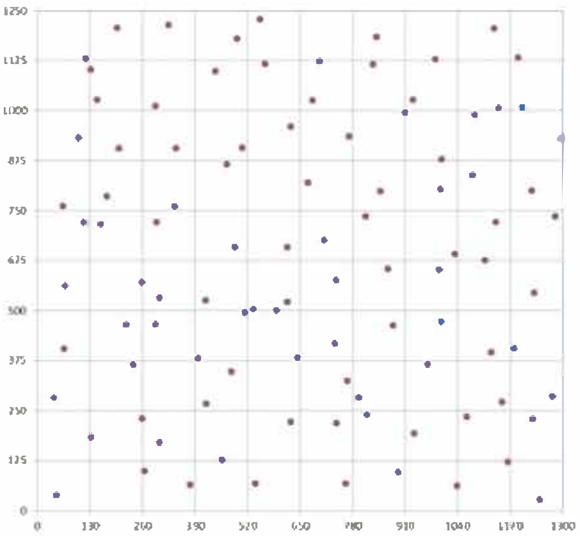

Figure 6 – Random pattern of holes

The formation of droplets giving the required intensity (rainfall rate) requires a head in the tray of only a few millimetres of water. Small increases in depth will lead to higher intensities of rainfall with the specified droplet size. An appreciable increase in the head of water would lead to stream flow and rely on this breaking up before impact on the sample to give individual droplets of a random size. The depth of water required is around 3 mm and so a 1 mm change is significant – this means that levelling the tray must be carefully carried out and maintained during the test. The laboratory test uses a drip tray whose area is only a fraction of the sample area and three test positions are required – not overlapping and offset from the centre the centre area to avoid symmetry. Thus, between 23% and 47% of the sample is exposed to simulated rain depending on the sample size (20 m² to 10m² respectively). The resulting sound intensity is found from measuring sound pressure and using equation K.1 or measured directly with a sound intensity probe and using equation K.4, in [2]:

Equation K.1

$$L_I = L_{pr} - 10\text{Log}\left(\frac{T}{T_0}\right) + 10\text{Log}\left(\frac{V}{V_0}\right) - 14 - 10\text{Log}\left(\frac{S_e}{S_0}\right)\ \text{dB}$$

Equation K.4

$$L_I = L_{Im} + 10Log\left(\frac{S_m}{S_e}\right)\ \mathbf{dB}$$

where:

L_{pr} is the energy averaged sound pressure (for the three test positions of the drip tray) in the test room, dB;

T is the reverberation time of the test room in seconds;

T_0 is the reference time (= 1 sec);

V is the volume of the test room in cubic metres (m³);

V_0 is the reference volume (= 1 m³);

S_e is the total of the areas of the sample excited by the rainfall in square metres, (m², corresponds to three times the perforated area of the drip tray;

S_0 is the reference area (= 1 m²);

L_{Im} is the sound intensity directly measured, dB;

S_m is the area of the measuring surface, m².

Making Predictions

The sound intensity radiated by the test roof sample is used to find the sound pressure in another space of known dimensions and reverberation time. Hopkins [7] demonstrates this process for skylights, giving two examples for the application to classrooms.

As mentioned in the previous section, the sound intensity reported from the test laboratory is for a partially excited roof sample and so must be modified as if the sound pressure was increased for the whole sample being exposed to rainfall. This is done using the expression:

Equation 1

$$L_{I(s)} = L_I + 10Log\left(\frac{S_s}{S_0}\right)$$

where:

$L_{I(s)}$ is the sound intensity if the whole sample was subjected to rainfall, dB;

S_s is the area of the test sample, m²;

S_0 is the reference area for the rainfall rate (=1 m²);

This assumes a linear relationship between the area excited by the rain and the sound generated – which may not be true, since the dynamic response of the roof sample will not be the same at every point.

If sound intensity was directly measured then providing that the measurement surface (S_m) is the whole roof sample area then that intensity (from ***equation K.4***) has been adjusted for the difference between exposure and measurement areas, but if the sample area is greater than the measurement surface area then a further adjustment is necessary as:

Equation 2

$$L_{I(s)} = L_I + 10Log\left(\frac{S_s}{S_m}\right)$$

The process is carried out for each of the one-third or octave bands as required by contractual requirements and requires detail of the reverberation times and absorption characteristics of the space(s) – [4] gives target values for RT based on room size, see ***Figure 3***, in [4], together with target values for specific learning spaces as shown in ***Table 1***.

Learning space	Reverberation time (s) – mid frequency average (RT_{MF})
breakout spaces/meeting spaces/teacher work spaces	0.4 – 0.5
flexible learning spaces	0.5 – 0.8
cellular classrooms	0.4 – 0.5
music learning spaces	0.6 – 0.8
halls/multipurpose spaces	0.6 – 0.8
gymnasiums	0.8 – 1.5
technology and science spaces	0.6 – 0.8
libraries	0.5 – 0.8

Table 1 *– Design reverberation times in different learning spaces*

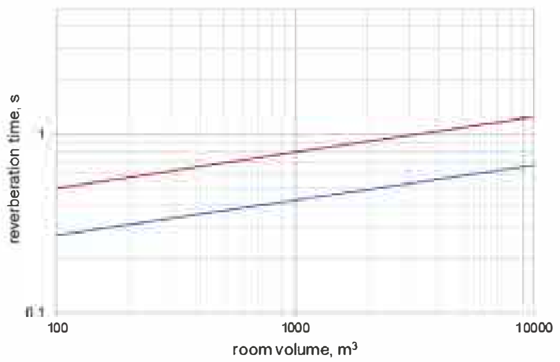

Figure 7 *– Reverberation times RTMF recommended in [4] as a function of room size*

A recent example for a school had multiple open learning spaces where the room volumes were around 850 m³ with floor areas each around 200 m². The value of RT_{MF} recommended in ***Figure 7*** and ***Table 1*** is 0.4 to 0.8 sec. The less absorption supplied the lower the cost of the room and so it is likely that designers would opt for the longer RT values and so 0.6 secs was used in the analysis for the frequency range 100 to 500 Hz and 0.4 sec for the 630 Hz to 5 kHz frequency range.

It should be noted that the Standard does not require the area of the sample to be stated in the report, only its description (Clause 6, ISO 10140-3:2010 and BS EN ISO10140-1 2016: Appendix K). The effect is obvious, since the sample area can vary between 10 m² and 20 m², then the difference in converting the reported intensities for sample size will be up to 3 dB. If the sample area is not given in manufacturers' data then one cannot do the conversion or even know that there is one to be made and so predictions will err.

Table 2 and ***Figure 8*** show an example for a metal roof over a SIP with a comparison between correcting or not correcting the intensities reported.

	From the test sample					
1/3rd Octave band freq, Hz	L_I	$L_{I(s)}$	L_w	$L_{p(in\text{-}situ)1}$	$L_{p(in\text{-}situ)2}$ corrected	$L_{p(in\text{-}situ)3}$ not corrected
100	40.5	50.6	73.6	55.6	58.0	46.2
125	40.9	51.0	74.0	56.0	58.4	46.6
160	41.7	51.8	74.8	56.8	59.2	47.4
200	44.4	54.5	77.5	59.5	61.9	50.1
250	44.7	54.8	77.8	59.8	62.2	50.4
315	44.7	54.8	77.8	59.8	62.2	50.4
400	46.1	56.2	79.2	61.2	63.6	51.8
500	45.4	55.5	78.5	60.5	62.9	51.1
630	40.0	50.1	73.1	55.1	55.8	44.0
800	27.4	37.5	60.5	42.5	43.2	31.4
1000	18.6	28.7	51.7	33.7	34.4	22.6
1250	14.0	24.1	47.1	29.1	29.8	18.0
1600	12.2	22.3	45.3	27.3	28.0	16.2
2000	9.8	19.9	42.9	24.9	25.6	13.8
2500	4.9	15.0	38.0	20.0	20.7	8.9
3150	1.5	11.6	34.6	16.6	17.3	5.5
4000	2.1	12.2	35.2	17.2	17.9	6.1
5000	3.8	13.9	36.9	18.9	19.6	7.8
				overall dBA = 62.1	**70.7**	**58.9**

Table 2 *– Application of test results for metal tray roof over a structural insulated panel roof, all values in dB*

Notes

1. *Calculated for the in-situ exposed roof area.*
2. *Calculated for in-situ exposed roof area and for natural rainfall.*
3. *Calculated from laboratory sound intensity with no correction for sample size.*

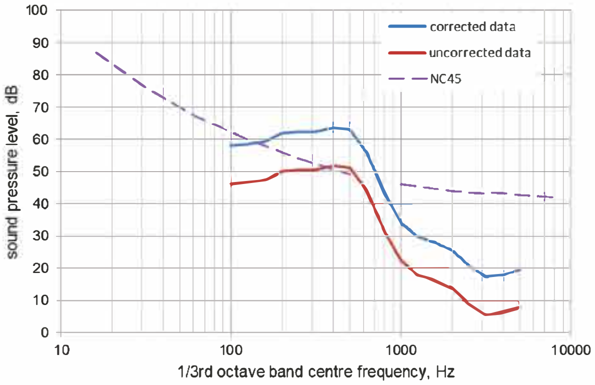

Figure 8 – Data from Table 2 plotted with NC45 curve

From ***Figure 8*** it is clear that if corrections are not made for either sample size and natural rain versus simulated rain then the prediction is that the roof system will almost meet the NC45 criteria. In contrast, the corrected data prediction is some 10 dB outside the requirements and additional treatments, such as a suspended ceiling, ceiling insulation, damping paints etc. are necessary.

Discussion and Conclusions

The consolidated theory for predicting rain noise, as presented by Griffin and Ballagh in 2012 [10], under-predicts for steel roofing by a considerable margin (7 dB for corrugated steel and 16 dB for metal tray.) Griffin presented a paper at a 2016 conference [6] in which he concluded *"In this context, the ability to evaluate the accuracy of rain noise predictions is currently limited as are the benefits of such prediction methods for evaluating a wide variety of construction types".* The context of which he spoke relates to the dearth of supporting data from laboratory tests. In other words, prediction methods have been developed but the results are poor and unable to be improved until more test data and laboratory inter-comparisons are available. Thus, to improve models we need to test, but the standards to which we test lack reproducibility due to loose prescription of the method, hardware and reporting requirements. Most of the issues raised in this paper have already been discussed by Chené et al [11] in 2010, before the addendum to Part 5 of 1SO 10140 was released (in 2014) and yet none have since been addressed. One imagines that the rain noise testing community is small so perhaps the way forward is to encourage it to cooperate. It is incumbent upon architects, consultants and others who specify roofing systems to ensure that the data supplied by roofing manufacturers is appropriate and is used in the correct manner.

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[1] https://www.youtube.com/watch?v=ldGUunu7pVI for example (accessed 20th Sept 2018)

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