State highway guide to acoustic treatment of buildings

Noise mitigation provided by the NZ Transport Agency is always within the road corridor where practicable, using low-noise road surfaces and noise barriers. If those measures are not practicable then the acoustic treatment of buildings, such as the provision of mechanical ventilation so that windows can be left closed, may be offered to residents where required by NZS 6806. This guide has been produced to inform the Transport Agency staff and contractors about factors involved in the selection, design and installation of acoustic treatment of buildings.

Version 1.0, June 2015

NZ TRANSPORT AGENCY
WAKA KOTAHI

Safer Journeys

New Zealand Government

CONTENTS

NZ Transport Agency
Published June 2015

ISBN 978-0-478-38086-6 (print)
ISBN 978-0-478-38085-9 (online)

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DOCUMENT MANAGEMENT PLAN

1. PURPOSE

This management plan outlines the updating procedures and contact points for the document.

2. DOCUMENT INFORMATION

DOCUMENT NAME	State highway guide to acoustic treatment of buildings
DOCUMENT NUMBER	SP/M/023
DOCUMENT AVAILABILITY	This document is located in electronic form on the NZ Transport Agency's website at www.nzta.govt.nz
DOCUMENT OWNER	Stephen Chiles
DOCUMENT SPONSOR	Rob Hannaby

3. AMENDMENTS AND REVIEW STRATEGY

All corrective action/improvement requests (CAIRs) suggesting changes will be acknowledged by the document owner.

ACTIVITY	COMMENTS	FREQUENCY
Amendments (minor revisions)	Updates incorporated immediately when they occur.	As required
Review (major revisions)	Amendments fundamentally changing the content or structure of the document will be incorporated as soon as practicable. They may require coordinating with the review team timetable.	At least biennially
Notification	All users that have registered their interest by email to environment@nzta.govt.nz will be advised by email of amendments and updates.	Immediately

RECORD OF AMENDMENT

AMENDMENT NUMBER	DESCRIPTION OF CHANGE	EFFECTIVE DATE	UPDATED BY

1

INTRODUCTION

1.1 BACKGROUND

The NZ Transport Agency aims to be a good neighbour, taking social and environmental responsibility seriously, including management of noise. This is reflected in external and internal strategy and policy documents that the Transport Agency is required to implement, including the Transport Agency's Environmental plan[01]. These documents are consistent with the requirements of the Land Transport Management Act 2003 and Resource Management Act 1991 (refer to figure 1).

The Transport Agency's Environmental plan sets formal objectives regarding noise from the state highway network, including:

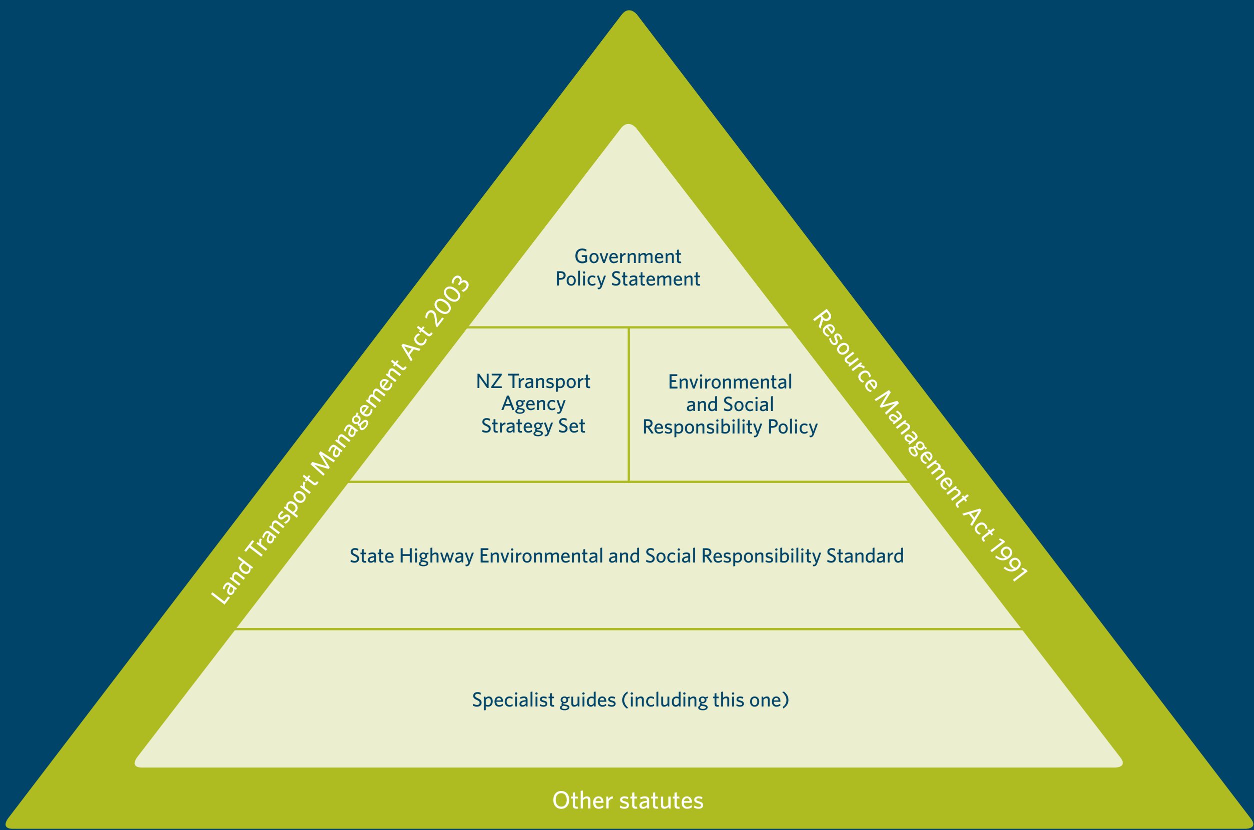
> N2 – Determine reasonable noise requirements when seeking new or altering existing designations including when designating existing local roads by using RMA procedures.

The Transport Agency has adopted New Zealand Standard NZS 6806:2010[02] when applying this objective. NZS 6806 requires the Transport Agency to investigate options for low-noise road surfaces and noise barriers in the road corridor to achieve specified criteria. These mitigation measures are preferred as they can provide appropriate road-traffic noise levels both inside and outside neighbouring houses. However, if these mitigation measures are not practicable, and noise levels are above the criteria in NZS 6806, the Transport Agency will offer to treat individual buildings, such as the provision of mechanical ventilation so that windows can be left closed. Acoustic treatment should be designed to achieve reasonable internal noise levels in accordance with NZS 6806.

01 Transit New Zealand (2008) *Environmental plan, version 2.* **www.nzta.govt.nz**

02 Standards New Zealand (2010) *NZS 6806:2010 Acoustics – road-traffic noise – new and altered roads.* **www.standards.co.nz**

FIGURE 1: RELATIONSHIP OF THIS GUIDE TO KEY POLICY AND STRATEGY DOCUMENTS



For existing roads, the Transport Agency's reverse sensitivity guidance[03] seeks for new houses to have appropriate acoustic treatment implemented by the developer/owner. The circumstances where acoustic treatment of buildings may be appropriate are set out in section 1.6 of this guide.

The term 'acoustic treatment of buildings' in this guide refers to measures designed to reduce road-traffic noise and its effects inside existing buildings. NZS 6806 defines this acoustic treatment as 'building-modification mitigation'. Building-modification mitigation includes the following measures:

- mechanical ventilation (so that windows can be kept closed)
- sound insulation
- building relocation
- voice amplification systems (eg for teachers in classrooms).

Building-modification mitigation is only required by NZS 6806 for 'habitable spaces' (refer to section 2.9), which are spaces associated with domestic living. However, acoustic treatment described in this guide is applicable to most protected premises and facilities (PPFs), which are defined by NZS 6806 as spaces in buildings used for:

- residential activities
- overnight medical care
- teaching (and sleeping in educational facilities)
- marae.

1.2 PURPOSE OF THIS DOCUMENT

This guide has been produced to help the Transport Agency staff and contractors assess when the acoustic treatment of buildings is appropriate in accordance with NZS 6806, and the effective design and practical implementation of mitigation measures. The aim of this guide is to help deliver fit-for-purpose noise mitigation measures and to standardise the approach to building-modification on Transport Agency projects. This guide may also help developers and home owners when they are building new houses near existing state highways, subject to the Transport Agency's reverse sensitivity guidance (see section 1.6 for more information).

This guide complements the:

- Guide to assessing road-traffic noise using NZS 6806 for state highway asset improvement projects[04]
- State highway noise barrier design guide[05]
- Guide to state highway road surface noise[06].

[03] NZ Transport Agency (in preparation) *Guide to the management of reverse sensitivity effects on the state highway network.*

[04] NZ Transport Agency (2011) *Guide to assessing road-traffic noise using NZS 6806 for state highway asset improvement projects, version 1.0.* **www.acoustics.nzta.govt.nz**

[05] NZ Transport Agency (2010) *State highway noise barrier design guide, version 1.0.* **www.acoustics.nzta.govt.nz**

[06] NZ Transport Agency (2014) *Guide to state highway road surface noise, version 1.0.* **www.acoustics.nzta.govt.nz**

FIGURE 2: NZ TRANSPORT AGENCY STATE HIGHWAY NOISE GUIDES

1.3 RELATED DOCUMENTS

There are various other guides and standards which address acoustic treatment of buildings to achieve appropriate indoor noise levels. This guide should be read in conjunction with those documents in the circumstances discussed below.

Building Code

Section 3 details the relationship between the Building Act, Building Regulations, Building Code and Compliance Documents. This section also sets out the ventilation requirements in Clause G4 of the Building Code, which are applicable if windows are to be kept closed and mechanical ventilation installed.

Clause G6 of the Building Code relates to sound insulation in buildings. As at 2014 it only covers sound insulation of internal walls and floors between separate household units, such as the wall between two adjoining apartments. However, in 2010 there was public consultation on a proposed revision to Clause G6[07], which would include a requirement for sound insulation of building envelopes/facades. Clause G6 would apply to new and altered houses built next to existing roads, rather than new and altered roads built next to existing houses, which is the subject of this guide. Given that both requirements should have the same end result, it would be appropriate for the technical methods to be consistent. At this stage the revision to Clause G6 has not been finalised and when it is implemented then this guide may need to be updated for consistency.

District plans

There are rules in district plans for many parts of New Zealand requiring new residential buildings to be insulated from existing (or permitted) external noise. These rules generally apply in areas where there is a particular noise source such as in town centres or by ports, airports and roads. Some of these rules are similar to the proposed revision to Clause G6 of the Building Code, in that they require acoustic treatment to result in indoor noise levels below a specified value. There are a variety of approaches adopted in district plans: specifying maximum internal noise levels; specifying the acoustic performance of the facade construction; or specifying the minimum physical construction type of the facade. All approaches are trying to achieve the same result. In situations where a house was required to be sound insulated by a district plan when it was built, it would be unlikely to require further acoustic treatment if the house is subsequently assessed under NZS 6806 for a new or altered road project.

Designing quality learning spaces: Acoustics

This Ministry of Education guide[08] provides guidance on acoustic design of educational buildings. While this Transport Agency guide provides advice which is generally applicable to all building types including schools, it focuses on residential buildings to meet the requirements of NZS 6806. Should acoustic treatment of schools be required to mitigate road-traffic noise then reference should also be made to this guide.

AS/NZS 2107

Australian and New Zealand Standard AS/NZS 2107:2000[09] recommends design sound levels in buildings. This includes residential buildings near major roads (table 1).

TABLE 1: AS/NZS 2107 DESIGN SOUND LEVELS

	Satisfactory	Maximum
Living areas	35 dB L_{Aeq}	45 dB L_{Aeq}
Sleeping areas	30 dB L_{Aeq}	40 dB L_{Aeq}

Reproduced from AS/NZS 2107:2000.

These recommended limits are consistent with the 40 dB $L_{Aeq(24h)}$ requirement of NZS 6806 for acoustic treatment (refer to section 2.9). Reference to AS/NZS 2107 is therefore not required when applying NZS 6806. For acoustic treatment of other building types such as schools or hospitals the recommended limits in AS/NZS 2107 should be considered.

07 Ministry of Business, Innovation & Employment (2010) *Consultation on proposals to change the Building Code requirements and associated documents for protection from noise.* **www.dbh.govt.nz**

08 Ministry of Education (2007) *Designing quality learning spaces: Acoustics.* **www.minedu.govt.nz**

09 Standards New Zealand (2000) *AS/NZS 2107:2000 Acoustics – Recommended design sound levels and reverberation times for building interiors.* **www.standards.co.nz**

1.4 CHOOSING THE RIGHT MITIGATION TECHNIQUE

The acoustic treatment of buildings should be considered as a secondary means of mitigating the effects of road-traffic noise, as it does not address outdoor amenity and often constrains future operation of the building in question. Also, acoustic treatment of buildings can be offered by the Transport Agency but might not necessarily be accepted by the building owners. Similarly, building-modification mitigation cannot be subject to ongoing control by the Transport Agency. The primary ways to mitigate road noise that should be considered first, if practicable, are:

- planning to avoid major roads near residential areas as far as practicable, and encouraging less noise-sensitive land uses near road corridors
- careful road design, including horizontal and vertical alignment, and where appropriate, tunnelling
- limited design gradients and speed management
- low-noise road surfaces
- noise barriers.

Determining what represents the most appropriate noise mitigation solution for any given project requires a range of expert input, including advice from acoustics specialists, urban designers and cost estimators (for consideration of value-for-money). Noise mitigation measures should be considered both individually and in combinations, as the optimum strategy may involve using a number of different measures.

1.5 WHAT ACOUSTIC TREATMENT DOES THE TRANSPORT AGENCY INSTALL?

The Transport Agency will install acoustic treatment to 'habitable spaces' (refer to section 2.9) where required by NZS 6806. In the majority of cases, mechanical ventilation (enabling windows to be kept closed) is the only building-modification measure required.

A common misconception is that 'double-glazing' is the primary solution to noise mitigation but in most cases it is not appropriate (refer to section 2.3). If windows do require treatment, achieving effective seals is usually more important than the glazing configuration. Furthermore, thin thermal double-glazing has relatively poor acoustic performance due to resonances.

Typically only those rooms facing the state highway will require treatment, so the mitigation installed by the Transport Agency would not extend to the whole house. Within a certain room, treatment might not be required for all elevations (refer to information on enhancements in section 4.2).

Once acoustic treatment is installed by the Transport Agency, it is handed over to the building owners who are then responsible for any ongoing operation, maintenance and renewal requirements.

1.6 WHEN IS ACOUSTIC TREATMENT REQUIRED?

The Transport Agency should only consider acoustic treatment of buildings where objective analysis shows it is required in order to meet noise criteria within buildings, as a consequence of a new or altered road. Acoustic treatment of buildings should only be considered where it is impracticable for structural mitigation measures (low-noise surfaces and barriers) to achieve the external noise criteria in NZS 6806.

Acoustic treatment of buildings is not used by the Transport Agency for buildings next to existing roads. However, building owners or developers may wish to implement acoustic treatment independently of the Transport Agency. In some instances this might relate to reverse sensitivity controls, as discussed on this page.

New roads

The Transport Agency has adopted the criteria and assessment method from NZS 6806 for noise from new roads. A guide[04] has been produced to inform Transport Agency staff and contractors about how to apply the NZS 6806 on state highway projects. Under this Standard, performance targets are used, and a number of different options for noise mitigation are assessed to determine the best practicable option. These options are subject to an integrated design process in which the costs and benefits of the mitigation is considered. In some instances the best practicable option is to maintain the 'do-minimum' design with no specific noise mitigation.

Acoustic treatment of buildings should only be implemented if external NZS 6806 criteria for 'categories A or B' cannot be achieved. Acoustic treatment of buildings can be an effective way of reducing indoor noise levels. It does not, however, reduce noise in outdoor areas, and on this basis should be thought of as the mitigation measure of last resort. Low-noise road surfaces and noise barriers should still be used to achieve the lowest practicable external noise levels prior to acoustic treatment of buildings.

Altered roads

Minor works, such as resurfacing, surface treatment and rehabilitation, are not classified as an altered road. Acoustic treatment of buildings should not be included as part of any such minor works.

The definition of 'altered road' is given in NZS 6806. A road is only considered under this category if the predicted change in noise levels exceeds certain thresholds, which will generally occur only with a significant alteration to the alignment.

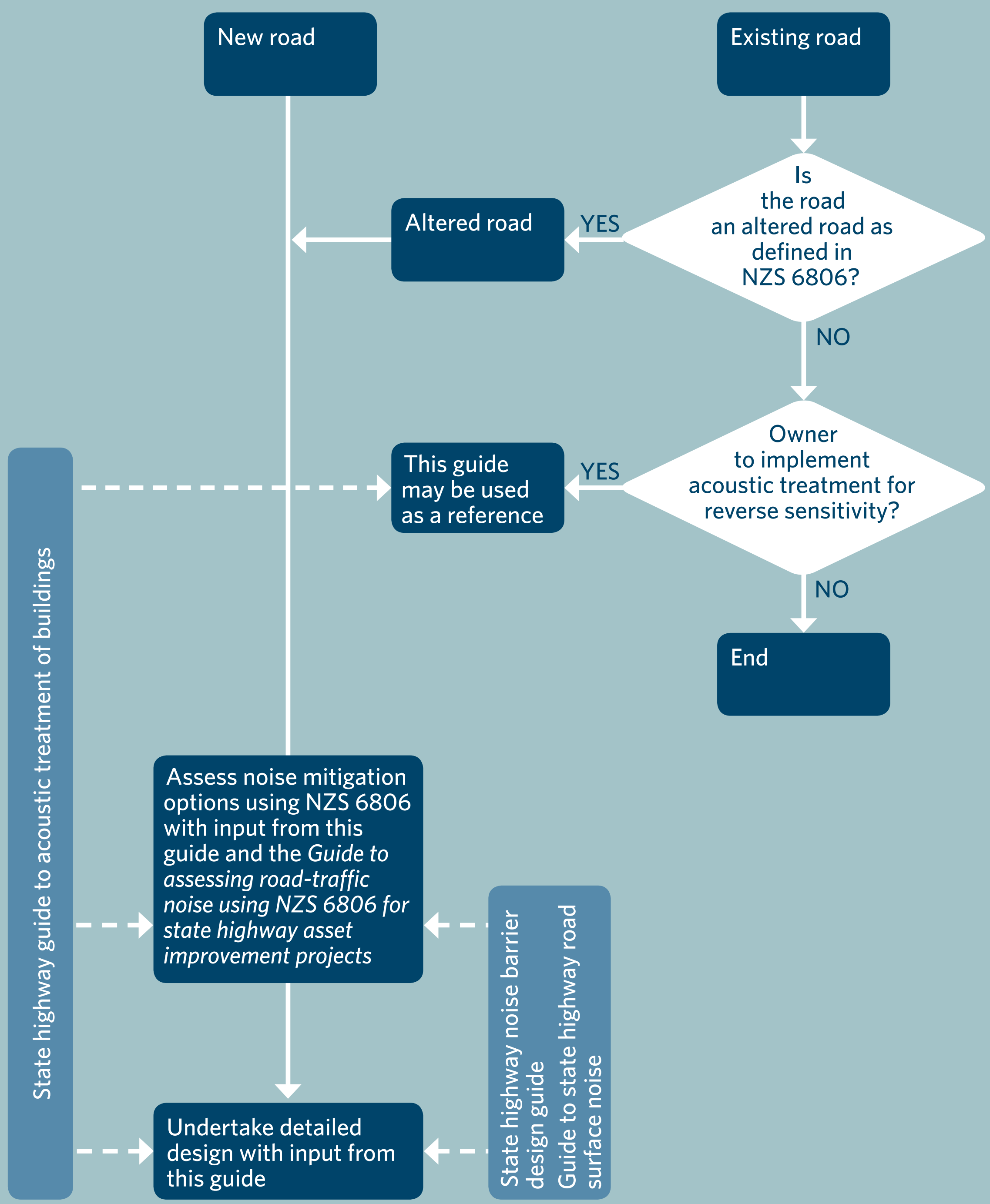
Works that meet the threshold to be considered as an altered road should be assessed by applying the noise criteria for altered roads within NZS 6806, in the same way as new roads. This will determine whether noise mitigation is required, including providing acoustic treatment of buildings.

Reverse sensitivity

Where new residential developments are proposed adjacent to an existing road the developer will often need to provide mitigation measures to reduce traffic noise levels received at the new development. This mitigation might include acoustic treatment of buildings, but the responsibility for this lies with the developer and not the Transport Agency. This issue is discussed in detail within the Transport Agency's reverse sensitivity guidance[03].

This guidance seeks to protect new residential developments from future as well as existing road-traffic noise. Therefore, if a road has been designated but not yet built, then new houses by the route would still require acoustic treatment. Also, if traffic is forecast to increase then acoustic treatment should be designed to account for the future traffic volumes.

FIGURE 3: USE OF THIS GUIDE WITHIN ROAD DESIGN PROCESS



2

ACOUSTIC DESIGN

2.1 TERMINOLOGY

The purpose of this section is to outline the basic principles associated with acoustic treatment of buildings for noise mitigation design. Further information on acoustics can be obtained from Wikipedia[10].

Sound sources cause changes in air pressure which are detected by our ears. These changes can also be measured by a sound level meter. The pressure changes are expressed in decibels, written as 'dB'. Being a logarithmic scale familiar mathematical rules for addition do not apply, eg 55 dB + 55 dB = 58 dB. An increase of 3 dB is a doubling of sound energy. However, in short-term tests a 3 dB increase is often only just perceptible to the human ear. As a rule-of-thumb a 10 dB increase corresponds approximately to a doubling of perceived loudness, eg 60 dB sounds twice as loud as 50 dB, although this also depends on the duration and characteristics of the sound.

The difference between the terms 'sound' and 'noise' is subjective, but generally speaking noise is defined as unwanted sound.

Sounds occur at different frequencies and, as our hearing is less sensitive to lower frequencies, measured levels are adjusted to correspond to human hearing. This adjustment is called 'A weighting' and is identified by the letter A, eg 60 dB $L_{Aeq(24h)}$.

10 Wikipedia, *Acoustics*. **www.wikipedia.org**

Road-traffic noise levels fluctuate and are typically assessed using A-weighted average values over a 24-hour period: $L_{Aeq(24h)}$.

Figure 4 provides an illustration of an average level. The $L_{Aeq(t)}$ is obtained from an 'energy' average of the decibel values over a given period of time (t); this results in a higher average level than normal arithmetic averaging. The average level represents the overall exposure to road-traffic noise, rather than the level of specific peaks as individual vehicles pass-by.

FIGURE 4: FLUCTUATING NOISE AND ITS AVERAGE NOISE LEVEL

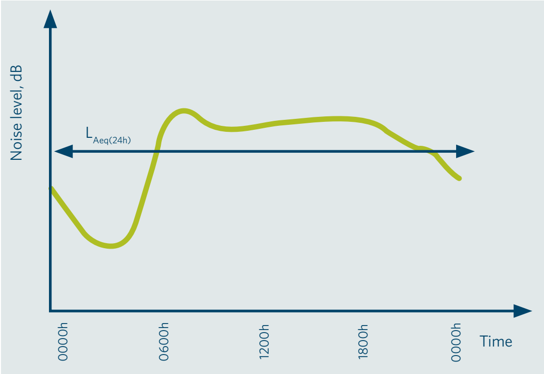
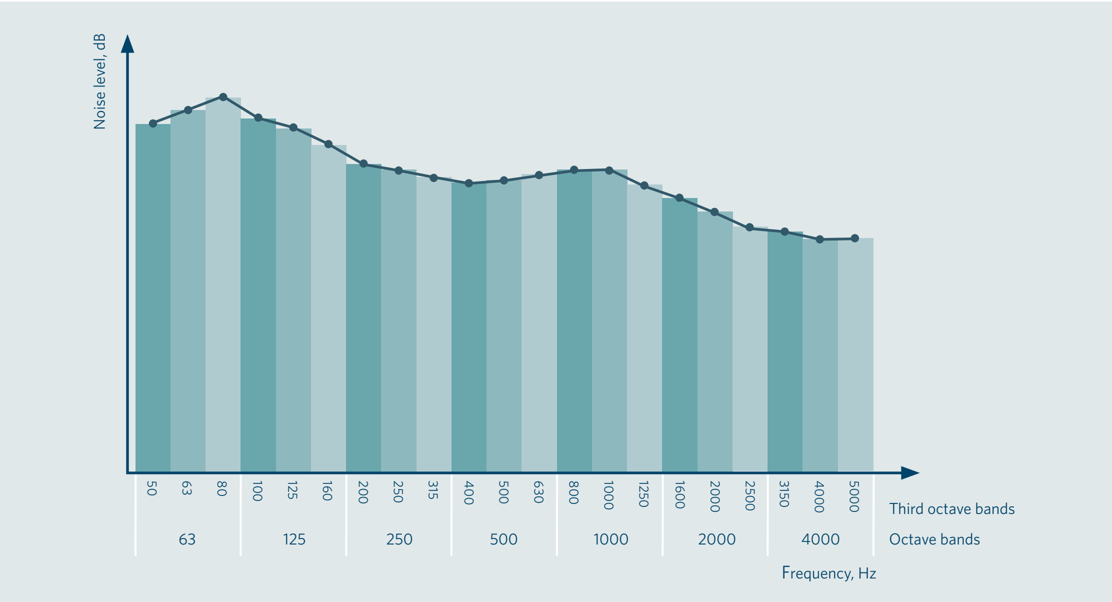


FIGURE 5: EXAMPLE ROAD-TRAFFIC NOISE SPECTRUM



Sound can occur across a whole range of frequencies, from low-frequency rumbles to high-frequency chirps, depending on how fast the air pressure changes are occurring. Frequency has the units of cycles per second or Hertz (Hz). Road-traffic noise is made up of a complex 'spectrum' of frequencies, which are often divided up into 'octave bands' or 'third octave bands'. For example, the 1000 Hz (1kHz) octave band covers the range from approximately 707 Hz to 1414 Hz. Figure 5 shows an example road-traffic noise spectrum, including characteristic low-frequency content.

Sound insulation

Noise propagation can be considered as a series of waves spreading out from a source, much like ripples spreading out from a pebble dropped into a pond. When road-traffic noise strikes a building some of the energy reflects back off the external surfaces, some is absorbed in the material of these surfaces and some is transmitted into the building. The noise level inside a building is a result of the following factors:

- **External road-traffic noise level**
- **Surface area (S)**

The greater the surface area of the building that is exposed to road-traffic noise, the greater the amount of energy transmitted into the building.

- **Sound reduction index (R)**

Building constructions reduce sound passing through them by varying amounts. The reduction can be tested under laboratory conditions to determine the 'sound reduction index', R. This is discussed further in section 2.2.

- **Acoustic absorption (A)**

Soft furnishings and other surfaces within a room absorb sound and can reduce the internal level experienced.

In figure 6 the quantity known as the 'level difference', D, is related to the sound reduction (R) of the facade, but decreases with larger facade surface areas (S), and increases with more absorption (A) in the room. R is the laboratory performance of a building element and D is the actual performance achieved on site.

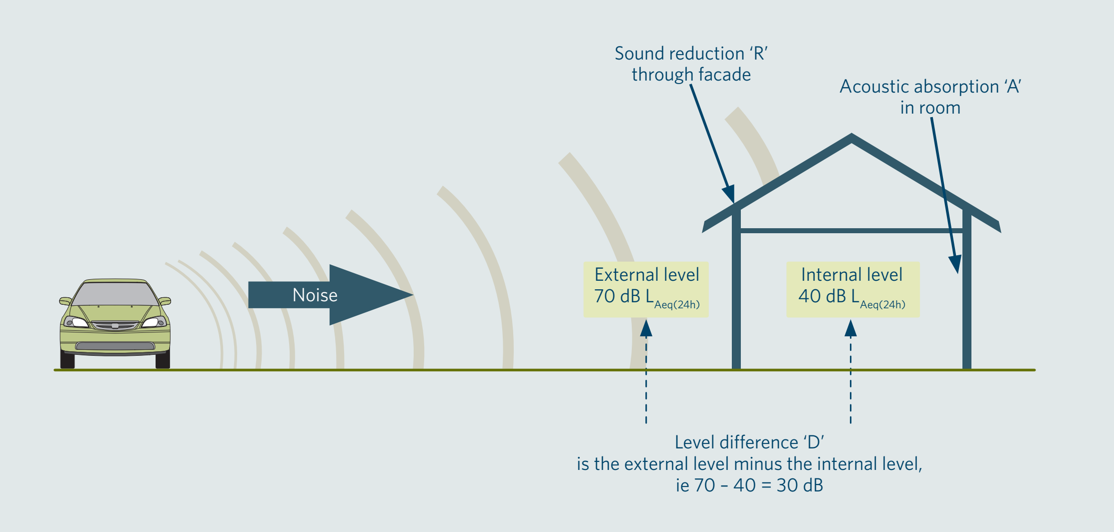
Both R and D are often used to define acoustic performance. However, there are numerous variations to the measurement and assessment methods and therefore R and D are usually followed by subscripted letters which define the quantity measured. Both R and D are measured in frequency bands but these can be combined to a single 'weighted' value denoted by a 'w' subscript (refer to section 2.2).

Values of D have been measured for typical New Zealand houses in a study[11] for the Building Industry Authority (now Ministry of Business, Innovation and Employment). It was found that for road-traffic noise these buildings had a level difference, D, of:

- 23–28 dB with windows closed
- 14–17 dB with windows ajar
- 8–12 dB with windows wide open.

11 G Bellhouse (2000) *Testing of the sound insulation of the external envelope of six houses.* **www.acoustics.nzta.govt.nz**

FIGURE 6: SOUND REDUCTION 'R' THROUGH FACADE WITH SURFACE AREA 'S'



2.2 SOUND REDUCTION INDEX

As discussed in section 2.1, the sound reduction index, R, of a building element can be measured in a specialist laboratory, such as at the University of Auckland[12] or the University of Canterbury[13]. The values of R are measured for each one-third octave-band, which can be compared to a standardised curve of a typical frequency characteristic to define the weighted sound reduction index, R_W. There are several variants of R_W, including the C_{tr} adaption term often used to take account of the low-frequency content of road-traffic noise.

R_W provides a quick way to assess the relative sound insulation provided by different constructions. However, more detailed assessment is normally required to account for the actual frequency response, and the actual site installation. This includes consideration of other elements in the facade, quality of installation actually achieved, surface area of the facade, and acoustic absorption inside the room.

12 University of Auckland, Acoustics Testing Service. **www.acoustics.auckland.ac.nz**

13 University of Canterbury, Acoustics Research Group. **www.mech.canterbury.ac.nz**

FIGURE 7: SOUND REDUCTION DATA AND CORRESPONDING R_W CURVE

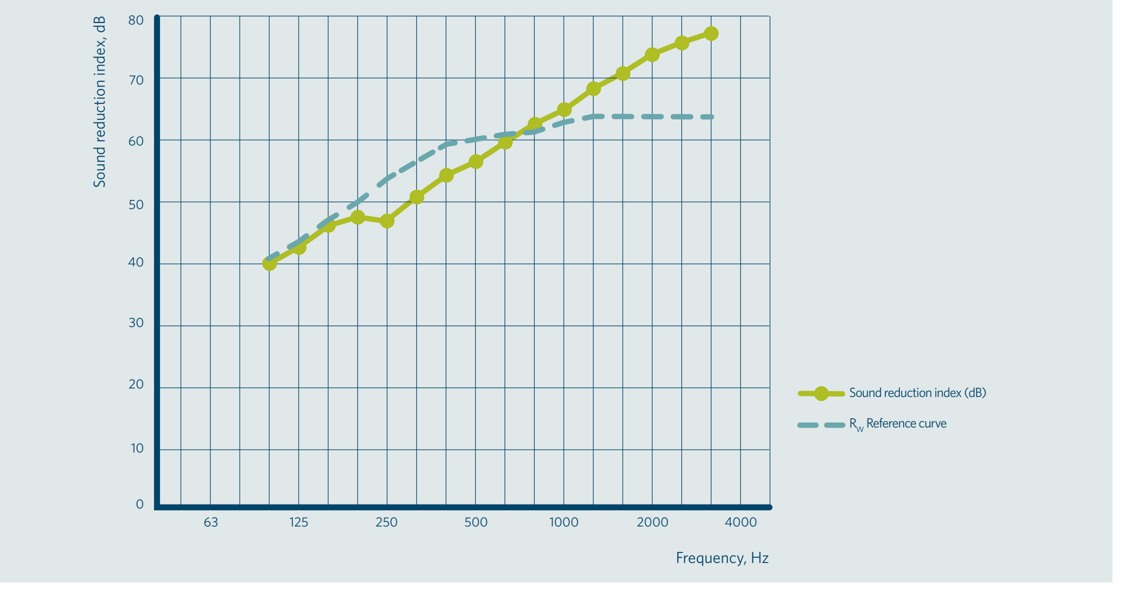
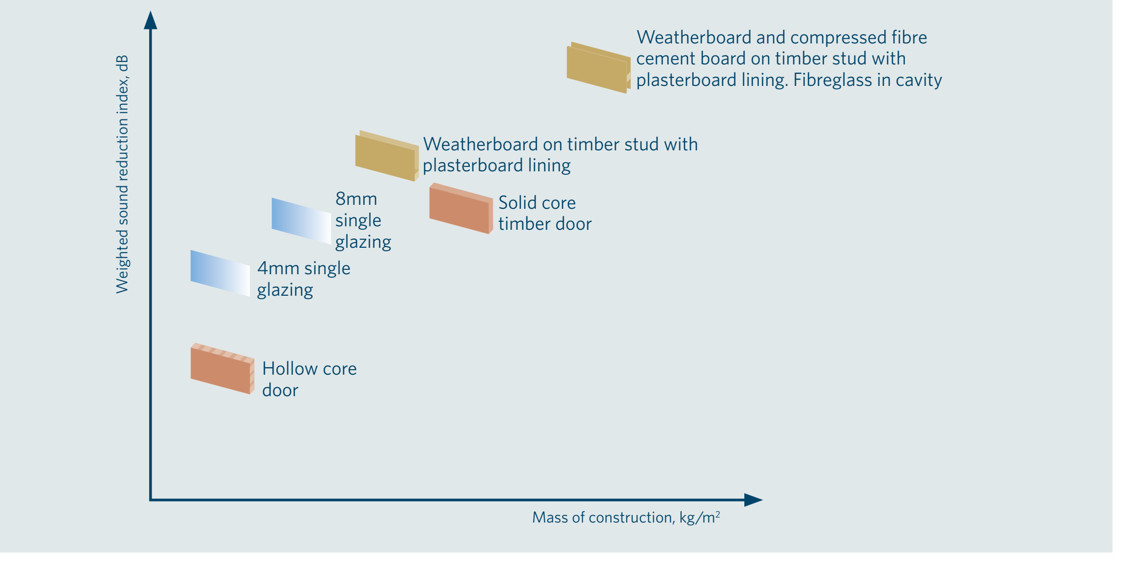


FIGURE 8: R_W SOUND INSULATION VALUES FOR BUILDING ELEMENTS



Composite sound reduction

A facade is usually made up of a number of different elements and the overall or 'composite' sound reduction can be determined from the individual sound reduction values of each component.

The composite sound reduction of a facade is significantly influenced by the weakest element, such as a window. This can be calculated exactly, or estimated from figure 9, which is based on the UK Department for Education and Skills, Building Bulletin 93[14].

A correction is obtained from figure 9 using the percentage of the facade occupied by the element with the lower sound reduction value (such as a window), and the difference between the higher and the lower sound reduction values. The correction is added to the lower sound reduction value to result in the composite sound reduction for the whole facade.

For example, figure 10 shows a facade with a total area of 10 m^2 which consists of:

- 8 m^2 of brick cladding with a plasterboard lining and fibreglass hung in the cavity giving R_W 60 dB,
- 2 m^2 window with a single 4 mm thick glazed pane giving R_W 29 dB.

The percentage of the facade occupied with the window is 20%. The difference in R_W is 31 dB. Reading from the chart gives a correction of 7 dB to be added to the lower R_W, giving a composite sound reduction value of around R_W 36 dB.

FIGURE 9: CHART TO ESTIMATE COMPOSITE SOUND REDUCTION

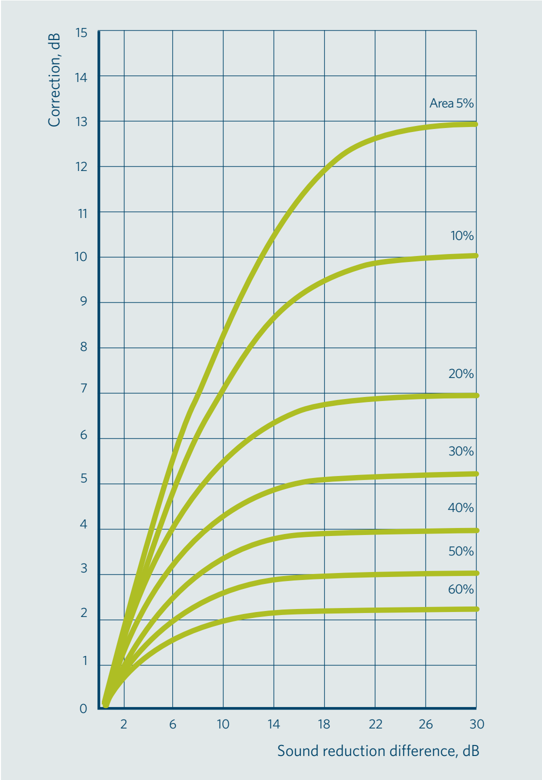
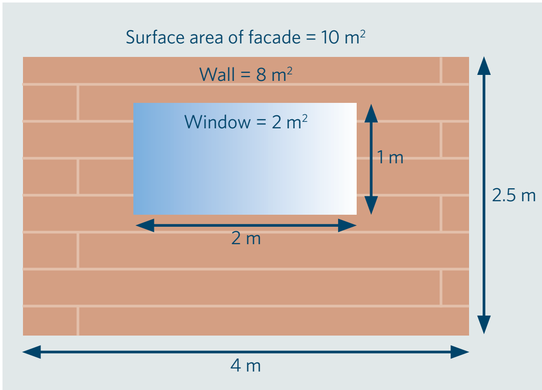


FIGURE 10: COMPOSITE SOUND REDUCTION VALUE EXAMPLE



14 UK Department for Education and Skills (2004) *Building Bulletin 93, Acoustic design of schools – a design guide.* **www.education.gov.uk**

2.3 WINDOWS

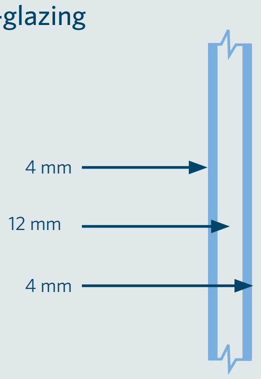
The most common misconception in the acoustic treatment of buildings is that 'double-glazing' is the solution. However, double-glazing does not remove the need to open windows for ventilation, and does not provide a substantial improvement compared to single glazing (refer to table 2). In the majority of cases providing ventilation by a method that avoids opening windows is the only treatment required to achieve an appropriate indoor noise level. The Transport Agency does not generally install double-glazing for noise mitigation. In the event that windows do require treatment, this section outlines the acoustics principles of glazing sound insulation for closed windows.

In general, the greater the mass of a building element, the better sound reduction it will provide. To an extent, the sound reduction of windows can be improved simply by increasing the thickness of the glass. However, the thickness/mass of the glass required to achieve a significant improvement soon becomes impractical and the performance is also affected by resonances in the glass. To avoid heavy panes, more efficient means of improving the sound reduction of glass are to:

- introduce a second pane, separated from the first pane by a cavity to form double or secondary glazing, or
- use laminated glass, ie glass with an internal layer such as polyvinyl butyral (pvb) in the middle of the two halves of the pane.

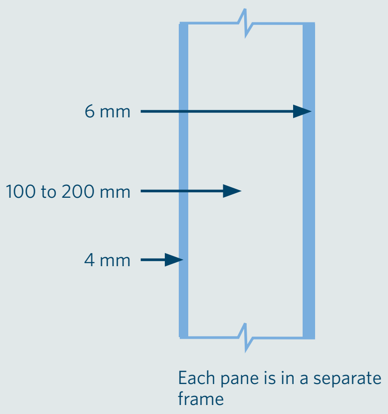
FIGURE 11: DOUBLE AND SECONDARY GLAZING

Double-glazing



- Sound reduction is significantly degraded by a resonance between the two panes and the narrow cavity (acting as an air spring).
- Good for thermal insulation rather than acoustic insulation.
- Commonly available and fits in standard frames (unless thick glass is used).
- Sound reduction can be improved to an extent by using two panes of different thickness, laminated glass or thick glass (non-standard or commercial grade frames may then be required).

Secondary glazing



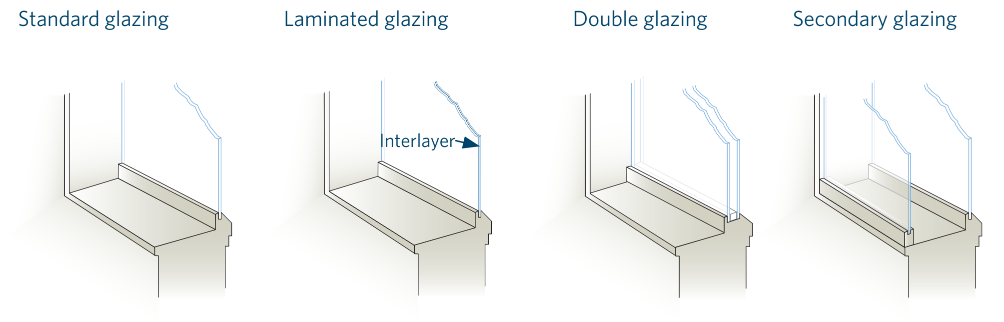
- Can result in high sound reduction, particularly with wider cavities (eg 200 mm).
- Does not provide effective thermal insulation due to air convection in the cavity, and often one of the 'panes' therefore actually needs to be double-glazed, resulting in three panes overall.
- Each half of the window can be in a standard frame, but the overall unit is usually a bespoke design.
- Requires acoustic absorption in the reveals between panes.
- Each pane opens separately and is therefore less convenient in operation for residents.
- Cavity is not sealed and therefore cleaning between panes can be an issue.
- Second pane can often be retrofitted behind an existing window.

TABLE 2: TYPICAL SOUND INSULATION PERFORMANCE OF GLAZING

Type	1st pane	Cavity	2nd pane	R_W
Single	4 mm			29 dB
Single	6 mm			31 dB
Single	10 mm			34 dB
Single (pvb laminate)	6 mm			33 dB
Single (pvb laminate)	10 mm			36 dB
Double	4 mm	12 mm	4 mm	31 dB
Double	4 mm	12 mm	6 mm	34 dB
Double	6 mm	12 mm	6 mm	33 dB
Secondary	4 mm	100 mm	6 mm	44 dB
Secondary	4 mm	200 mm	6 mm	48 dB

Note: The data in this table are indicative only and Rw values vary slightly between manufacturers for the same nominal thickness of panes. The values are dependent on the complete window system including the frames.

FIGURE 12: GLAZING TYPES



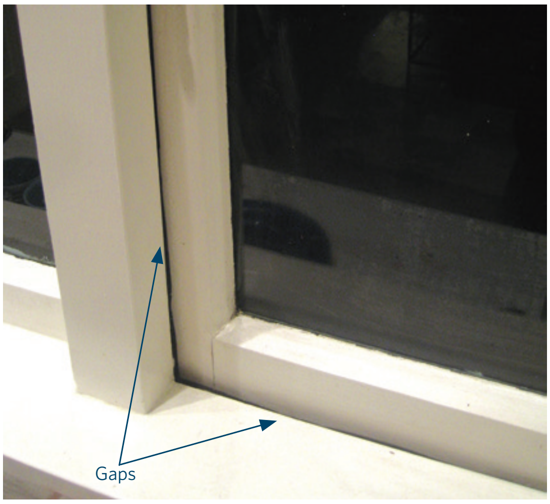
Window frames

The acoustic performance of a closed window is a result of the combination of glass, seals and frame. The performance of the frame depends on the air tightness provided by the seals, and the construction of the frame itself. Older windows or windows that are poorly installed and/or have missing or substandard seals lead to gaps that can both be draughty and significantly reduce acoustic performance.

In situations where poorly sealed windows need to be treated to achieve appropriate internal road-traffic noise levels, options are:

- retrofit/replace the window seals and/or fasteners (this might not be practical/effective for some types of windows and old frames), or
- replace the entire windows, including the surrounding frame.

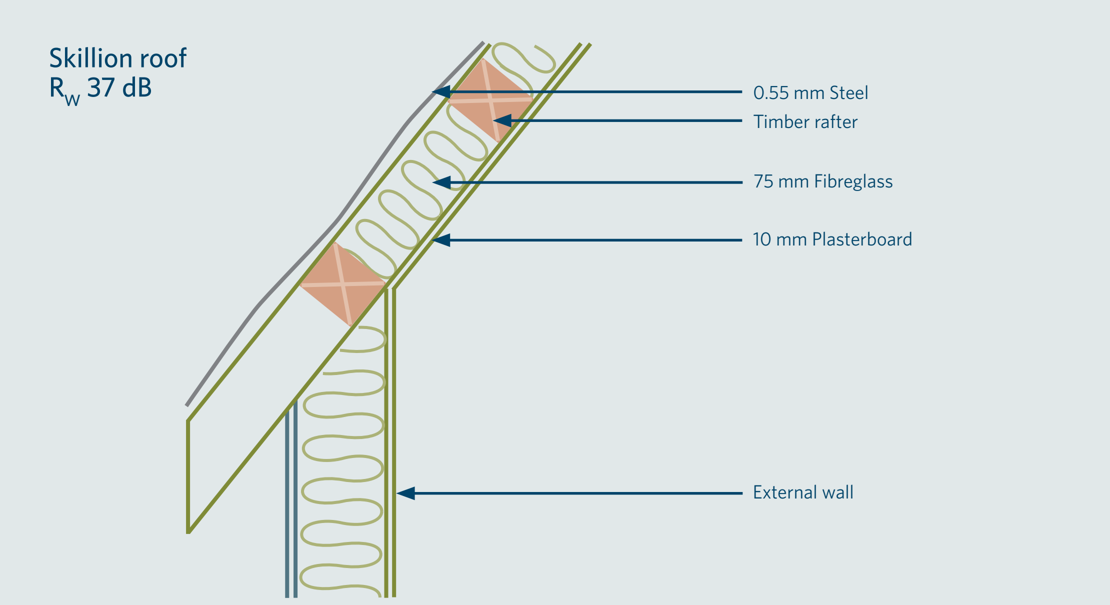
FIGURE 13: POORLY SEALED WINDOW FRAMES



2.4 WALLS AND ROOFS

External walls and roofs generally do not require treatment for road-traffic noise. The sound reduction of some indicative constructions are shown below:

FIGURE 14: SOUND INSULATION OF DIFFERENT TYPES OF ROOFS



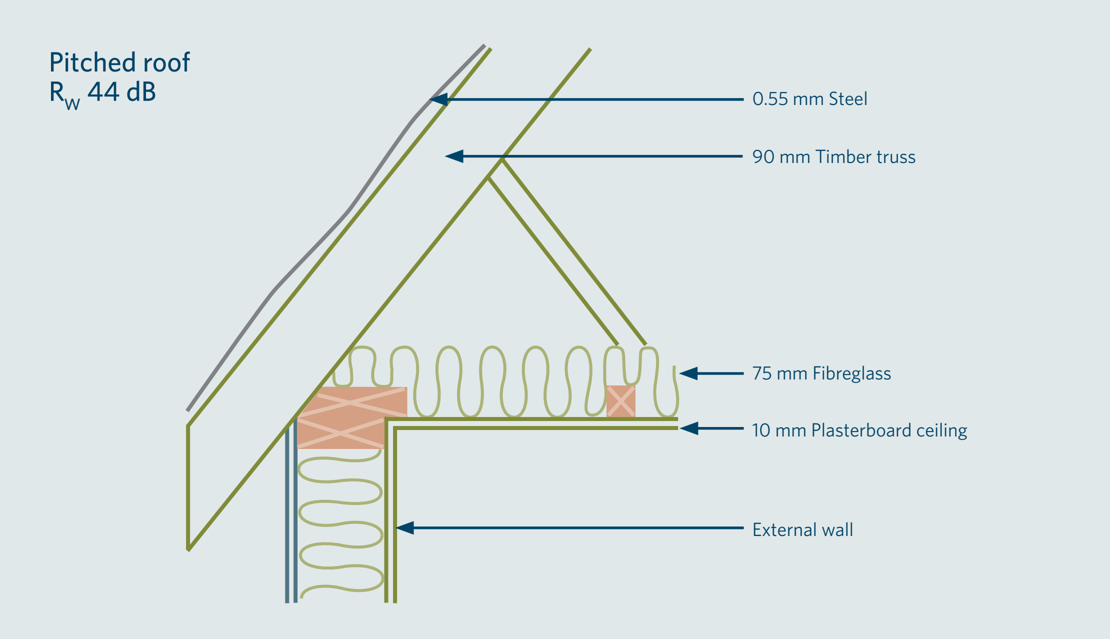
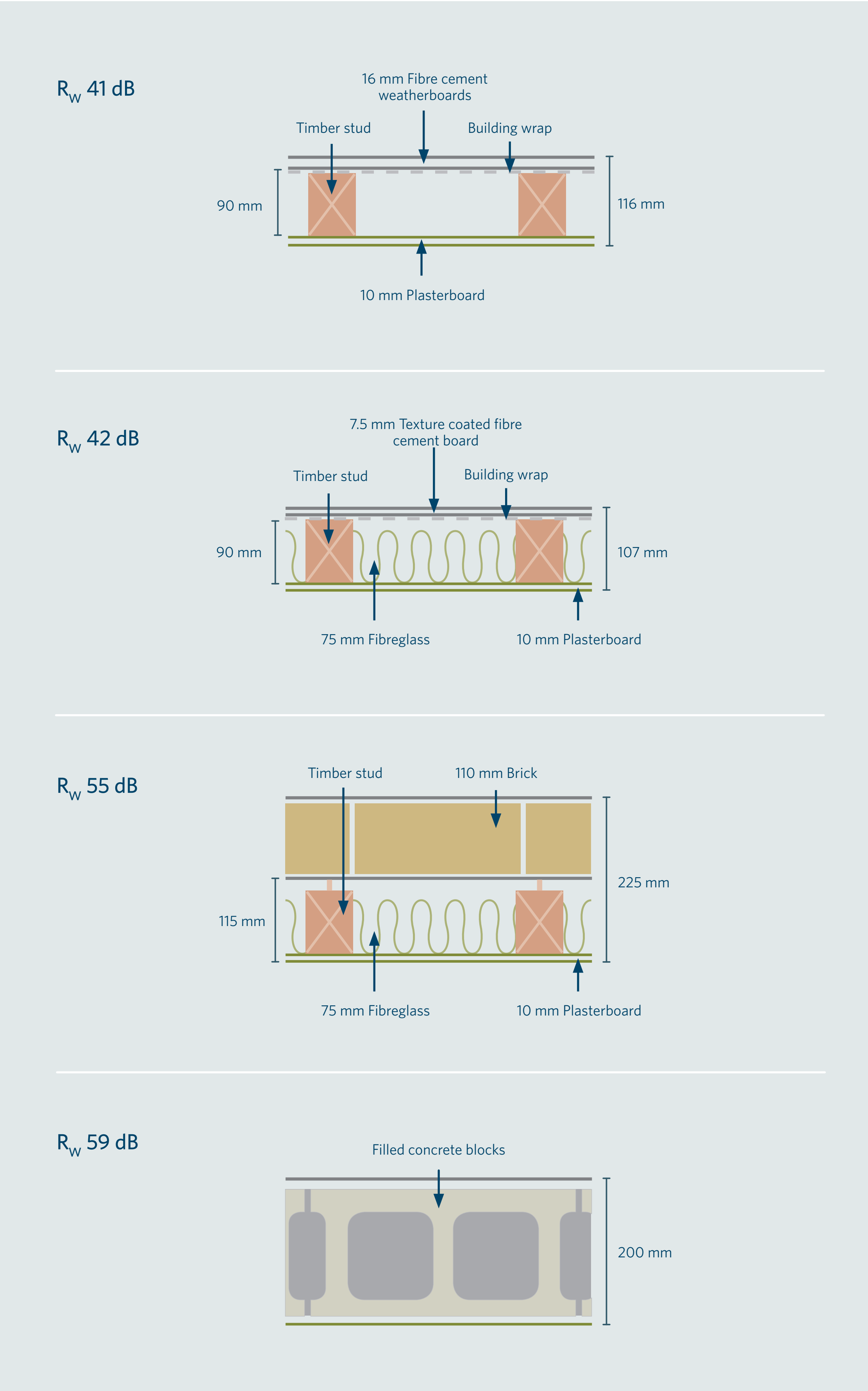
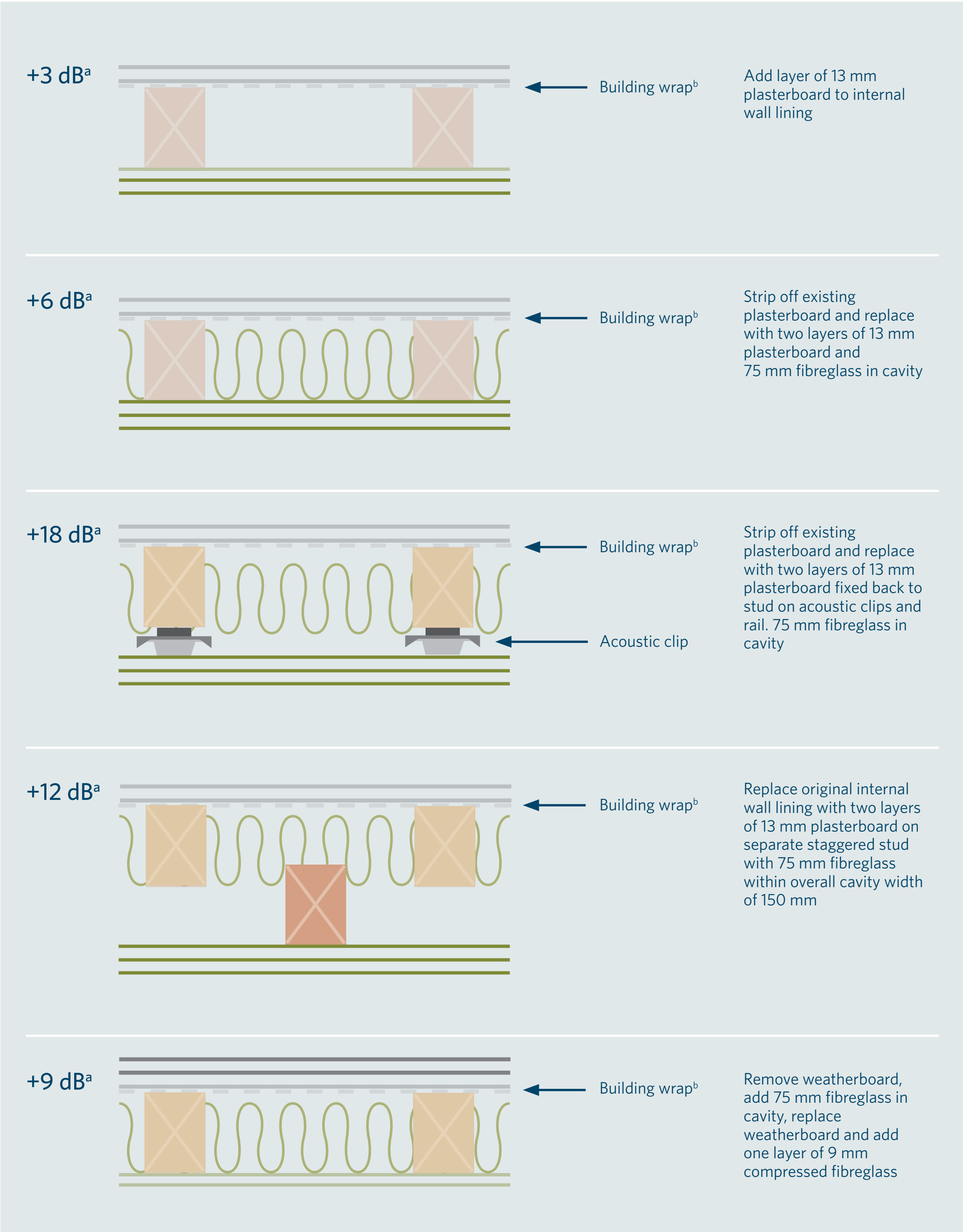


FIGURE 15: SOUND INSULATION OF DIFFERENT TYPES OF WALLS



While not often required, retrofitting walls and roofs with acoustic treatment is disruptive as it usually involves relining the room. The following examples of treatment show the improvements to the R_W value of a basic wall with 16 mm fibre cement weatherboard, and 10 mm plasterboard, either side of a 90 mm stud with no thermal insulation (R_W 41). For all the other wall and roof types shown on the previous pages similar treatments are applicable, although the performance improvement will vary depending on the initial construction.

FIGURE 16: ACOUSTIC TREATMENT OPTIONS AND R_W VALUES



Notes

[a] Change in R_W as a result of an improvement to an existing wall comprising 16 mm fibre cement weatherboard and 10 mm plasterboard either side of a 75 mm stud with no thermal insulation.

[b] If there is no existing building wrap and modifications are only required to internal linings, then the specific proposal should be discussed with the Building Control Authority before proceeding.

2.5 DOORS

For road-traffic noise mitigation, doors do not need to be considered in residential buildings unless they open directly into a habitable space (refer to section 2.9). For glazed bi-fold doors and ranch sliders the discussion on windows in section 2.3 is applicable.

A door, or more specifically a 'doorset', consists of a door leaf, frame and seals. Doorsets typically provide a greater level of sound reduction than windows or ventilation openings, but are still relatively weak compared to a wall or roof. The heavier the door leaf, and the tighter the air seal between the leaf and the frame, the greater the sound insulation performance of the doorset. Penetrations to the door such as key holes and glazed vision panels need to be carefully designed to maintain the overall sound reduction performance of the doorset.

For acoustic performance effective seals should be provided at the jambs and head of the door frame. For a performance up to R_W 30 dB the threshold should be cut close to the floor, but for higher performances a threshold seal is also required. A twin leaf door should also have a seal at the meeting stile, which should ideally be rebated. Note that fire seals on doors are generally not effective acoustic seals, and often separate fire and acoustic seals will be required in parallel. Most acoustic seals are a compressible neoprene or similar material. Suppliers of acoustic seals are listed on the Transport Noise website (www.acoustics.nzta.govt.nz).

For a performance of R_W 35 dB or above a doorset should ideally be procured as a complete door and frame assembly to ensure an exact fit and seal. However, there are many types of seal available that can be used to improve the sound reduction of existing doors.

Heavy and well-sealed acoustic doors can be difficult to open. If the force needed for people with limited strength or range of motion to open a door is prohibitive then mechanical actuators may be required. Careful design is also required to prevent raised threshold seals causing a trip hazard.

FIGURE 17: DOORSET AND DOOR SEALS

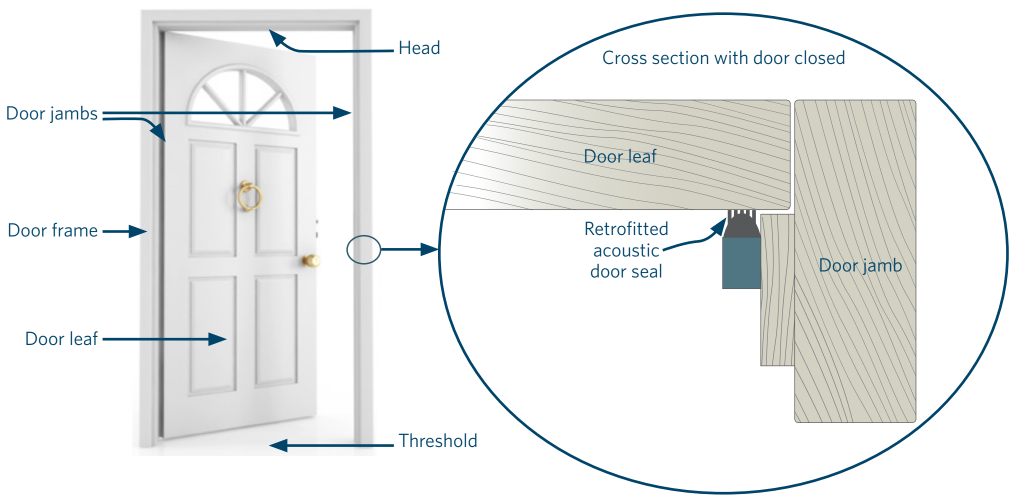


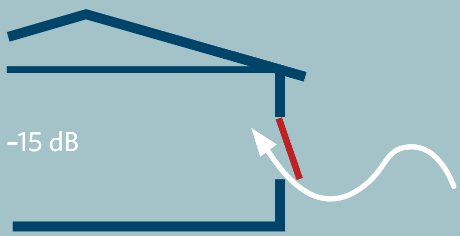
TABLE 3: SOUND INSULATION OF DIFFERENT TYPES OF DOORS

Door configuration	R_W
44 mm thick hollow core door without seals	15 dB
44 mm solid core door with seals	30 dB
54 mm solid core door with seals	35 dB

2.6 VENTILATION

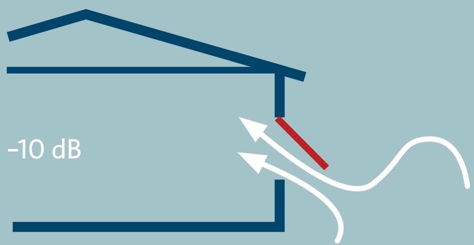
The overall sound reduction of a facade is determined mainly by its weakest elements. In most cases, the weakest elements are ventilation openings such as windows through which natural ventilation is provided. Mechanical ventilation allows windows to be kept closed which can significantly improve sound reduction. However, if a lesser improvement will suffice then it may be possible to maintain natural ventilation but enhance the sound reduction using the methods discussed below. These methods still require detailed ventilation design, as options such as staggered openings or trickle vents will generally not provide sufficient air movement for thermal comfort unless used in conjunction with other systems. Alternatively, openings can be kept on the facade of the building not facing the road.

FIGURE 18: PARTIALLY OPEN WINDOW



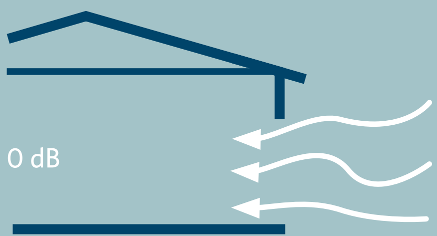
The primary means of providing natural ventilation is to open a window. A window partially open (nominally 100 mm opening) for ventilation can reduce noise from outside to inside by approximately 15 dB. This means that an external level of 55 dB can still result in an internal level of 40 dB, even with a window open for ventilation.

FIGURE 19: OPEN WINDOW



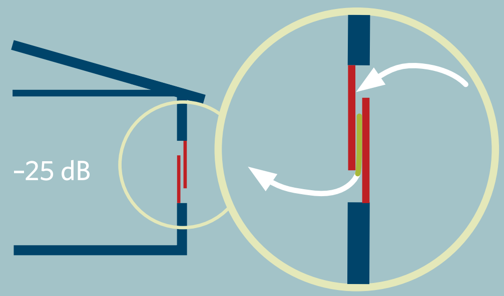
If the window were opened more fully, but still fixed to a restraining latch for example, then the performance decreases to a reduction in noise level from outside to inside of typically 10 dB.

FIGURE 20: BI-FOLD DOORS / RANCH SLIDER



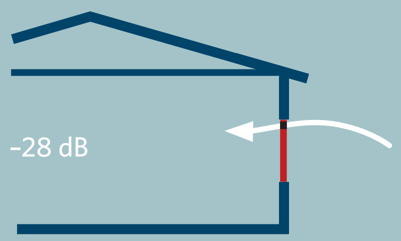
Fully open bi-fold doors or ranch sliders provide no sound reduction and the internal noise level would correspond closely to the external level. This is not a configuration included in the assessment of road-traffic noise. The figure is for an opening across the entire wall resulting in no reduction in noise level.

FIGURE 21: STAGGERED OPENINGS



By using a system of staggered opening panes, with acoustic absorption on the reveals between the panes, it is possible to reduce noise from outside to inside by approximately 25 dB. This means that an external level of 65 dB can still result in an internal level of 40 dB, even with a window open for ventilation.

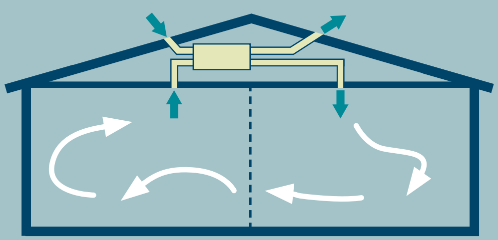
FIGURE 22: ACOUSTIC TRICKLE VENT



Acoustic trickle vents include a labyrinth arrangement and acoustic absorption around the air path. This provides ventilation with improved sound reduction. Acoustic trickle vents are available either as adaptations of standard trickle vents that fit above or within window frames, or as separate units fitted into the wall. Wall units can provide better sound reduction as they have more space for acoustic absorption. Section 3.2 provides further description. This type of system that enables windows to be kept closed can achieve a performance of approximately 28 dB, although this may be limited by other elements of the building construction.

Suppliers of trickle vents are listed on the Transport Noise website (www.acoustics.nzta.govt.nz).

FIGURE 23: MECHANICAL VENTILATION



Mechanical ventilation systems can provide a new path into a house for road-traffic noise, through the intake and exhaust ductwork. Depending on the level of external noise and locations of the grilles, sound absorbing lining or splitters are likely to be required in the ductwork, to attenuate noise passing through it. This attenuation can also serve to control fan noise in rooms.

2.7 BUILDING RECONFIGURATION AND RELOCATION

Acoustic planning and zoning of a site to minimise noise is more easily implemented when building a new development. However, the principles can still be applied to refurbishment. It may prove more cost effective to relocate activities rather than install acoustic treatment of building elements. These measures should be considered in the hierarchy of other options discussed in section 1.4.

Reconfiguration

When considering external noise such as that from road-traffic, it is preferable to locate noise-sensitive rooms away from the source, to the quietest areas. The least noise-sensitive activities can then be sited in the areas subject to most noise, thereby acting as a noise buffer (figure 25). For example, it may prove possible to reconfigure rooms within a dwelling so that a kitchen or bathroom is located on the noisiest facade, allowing bedrooms and living rooms to be relocated to a quieter facade. Within a school it may be possible to use a corridor or store rooms as noise buffer to a classroom[08] (figure 24).

Relocation

Another viable alternative for some small timber-framed buildings can be to relocate them. Figure 26 illustrates the benefits of noise attenuation over distance.

FIGURE 24: CORRIDOR ACTING AS NOISE BUFFER TO CLASSROOM

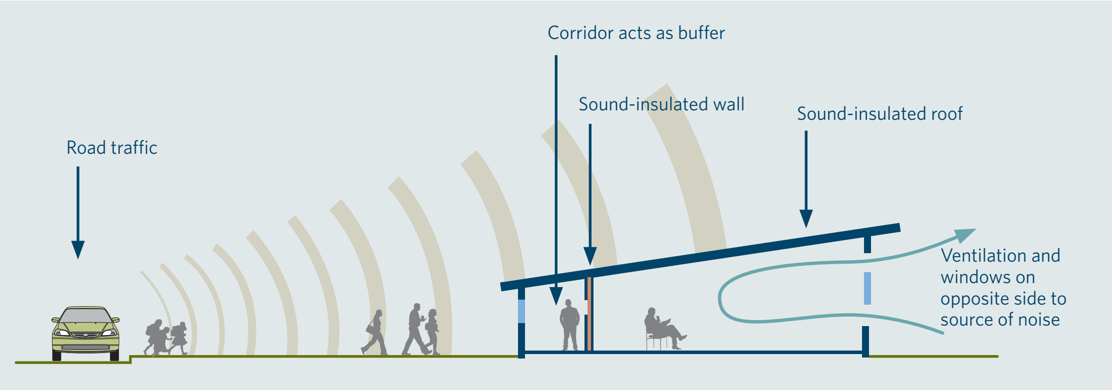


FIGURE 25: ILLUSTRATIVE NOISE MAP SHOWING SCREENING BY BUILDINGS

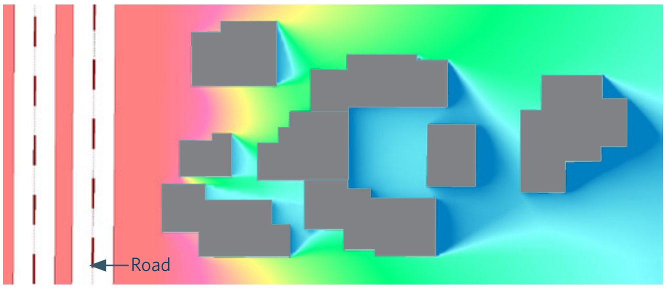
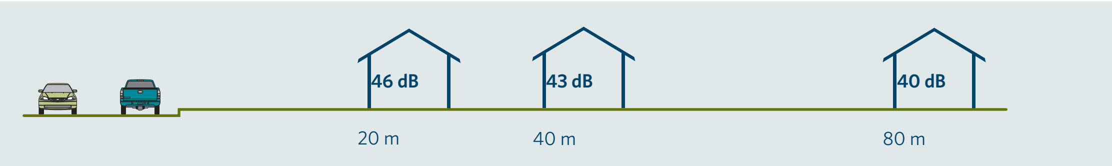


FIGURE 26: DECREASE IN ROAD-TRAFFIC NOISE WITH DISTANCE



2.8 VOICE AMPLIFICATION

For teaching spaces the best practicable option should be adopted for acoustic treatment to reduce internal road-traffic noise to levels recommended in AS/NZS 2107. If these levels cannot be complied with then the use of voice amplification or 'soundfield' systems should be considered to ensure the teacher's voice can be adequately heard above the noise. These are similar to traditional public address systems, but generally use a wireless headset microphone for the teacher, to make the system more flexible, and require distributed loudspeakers for even coverage. A soundfield system ensures that the speech is delivered to all parts of the room at an appropriate level above background (road-traffic) noise. Regardless of road-traffic noise levels such systems are already in use as a matter of course in some mainstream schools and schools for students with special hearing requirements.

The components of these systems are typically:

- a microphone system with radio transmitter
- a radio microphone receiver
- a mixer/amplifier
- loudspeakers.

Soundfield systems do not perform well in rooms that are too 'reverberant/live'. Acoustic absorption, such as ceiling panels, may need to be installed prior to any soundfield system.

Further details of soundfield systems are provided in the UK Department for Education and Skills, Building Bulletin 93[14].

FIGURE 27: SCHEMATIC DRAWING OF SOUNDFIELD SYSTEM

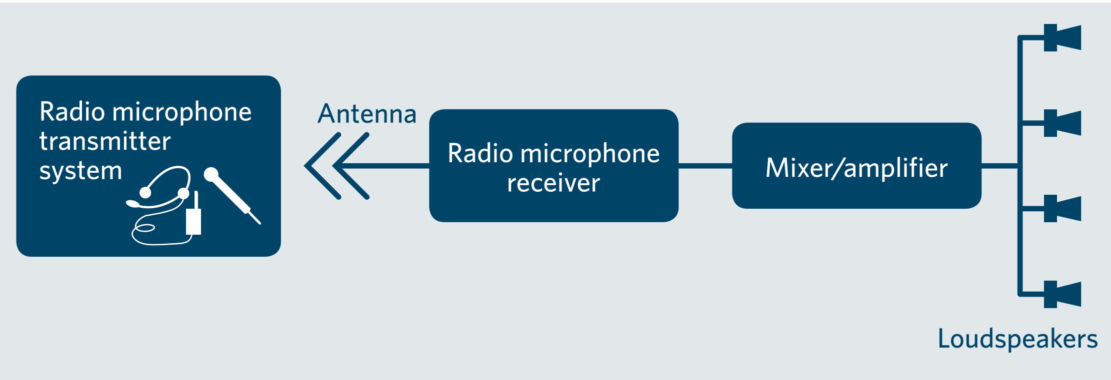


Photo courtesy of Oticon Soundfield/GoFrontRow

2.9 NZS 6806

NZS 6806 requires assessment of noise at all protected premises and facilities (PPFs) within 100 m of a new or altered road in an urban area, and within 200 m in a rural area. PPFs are houses and other buildings used for:

- residential activities
- marae
- overnight medical care
- teaching (and sleeping in educational facilities).

NZS 6806 does not set noise limits. Instead, it gives noise criteria under categories A, B and C and requires that the Best Practicable Option (BPO) be identified to mitigate road-traffic noise. The categories are used as a framework for assessing different mitigation options. This process promotes integrated design encompassing a wide range of factors as well as noise levels.

The upper category (C) provides a backstop against adverse health effects such as sleep disturbance, by requiring treatment of buildings in the event that external noise would not be sufficiently reduced using structural mitigation such as low-noise road surfaces and noise barriers. These buildings are referred to as 'Category C buildings' and the treatment is called 'building-modification mitigation'.

For houses in Category C, the requirement for building-modification mitigation applies to all habitable spaces, which are defined in the New Zealand Building Code and NZS 6806 as: a space used for activities normally associated with domestic living, but excluding any garage, bathroom, laundry, toilet (water closet), pantry, walk-in wardrobe, corridor, hallway, lobby, clothes-drying room or other space of a specialised nature occupied neither frequently nor for extended periods. In effect, the main spaces to be considered are bedrooms and living rooms.

TABLE 4: NZS 6806 SECTION 6, TABLE 2

Category	Criterion	Altered roads	New road	New road > 75,000 AADT (Auckland)
A	Primary	64 dB $L_{Aeq(24h)}$	57 dB $L_{Aeq(24h)}$	64 dB $L_{Aeq(24h)}$
B	Secondary	67 dB $L_{Aeq(24h)}$	64 dB $L_{Aeq(24h)}$	67 dB $L_{Aeq(24h)}$
C	Internal	40 dB $L_{Aeq(24h)}$	40 dB $L_{Aeq(24h)}$	40 dB $L_{Aeq(24h)}$

3

VENTILATION OF BUILDINGS

3.1 CRITERIA

The most common form of building-modification noise mitigation is the provision of mechanical ventilation so that windows can remain closed. This section discusses ventilation criteria and provides an overview of design options and considerations.

Legal requirements

The hierarchy of documents relevant to building ventilation is shown in figure 28[15]. This section provides a brief summary of requirements from these documents to illustrate the considerations involved when providing noise mitigation. However, the requirements are complex, and ventilation systems should always be designed by a suitably qualified person with reference to the actual documents.

CLAUSE G4

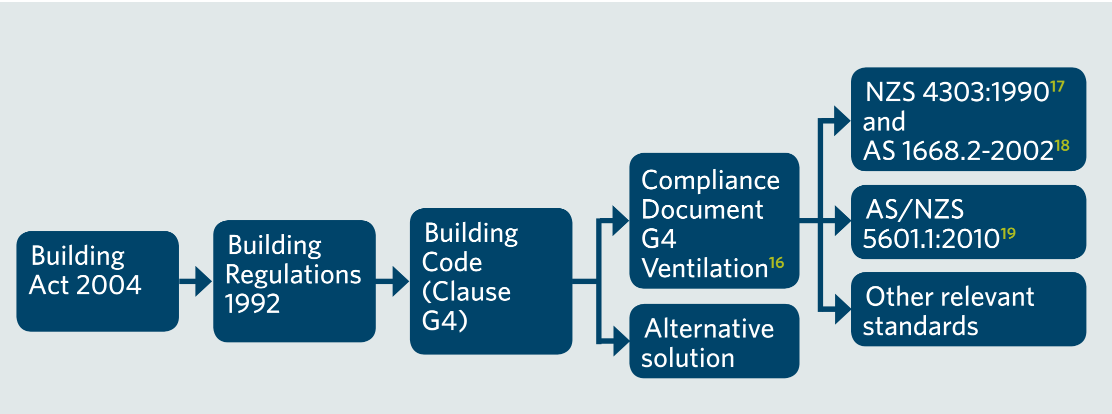
The objective of Clause G4 of the Building Code is to safeguard people's health by introducing 'fresh' air into a building. The method of ventilation used must be 'adequate' for the maximum expected occupancy and intended use. In addition, Clause E2.2 makes provision to safeguard occupants from the ingress of external moisture through a ventilation system.

COMPLIANCE DOCUMENT

The Compliance Document provides a 'Verification Method' and an 'Acceptable Solution', either of which can be used to meet the objective of Clause G4, by natural or mechanical ventilation, or a combination of both. Some key elements of the Acceptable Solution are:

- Where natural ventilation is used in privately owned occupied spaces, the net openable area of windows and other openings to outside must equal at least 5% of the building's floor area. Requirements differ for household units with a single external wall, and further requirements are specified for commercial and industrial buildings.
- Compliance with NZS 4303:1990 or AS 1668-2:2002 for ventilation design of private single and multiple dwellings. NZS 4303 specifies airflow rates of 0.35 air changes per hour (ACH) and a minimum of 7.5 litres/second per person in a dwelling. Other airflow rates apply to kitchens, bathrooms and toilet extracts.
- Design of air extract and air discharge to the outside is to be compliant with AS 1668-2.
- Where mechanical ventilation is used, requirements include the rates of supply and extract air, locations of supply and exhaust grilles, air filtration and recirculation and provisions for installation and commissioning.
- Compliance with AS/NZ 5601.1:2010 for ventilation in spaces with a fixed combustion appliance such as gas burning stoves and fireplaces. This requires additional ventilation to account for the consumption of air in the space and a prescribed level of extraction due to the introduction of air contaminants.

FIGURE 28: DOCUMENT HIERARCHY RELEVANT TO VENTILATION OF BUILDINGS



15 Ministry of Business, Innovation & Employment, Building law in New Zealand. **www.dbh.govt.nz**

16 Ministry of Business, Innovation & Employment (2014) *Acceptable Solutions and Verification Methods for New Zealand Building Code Clause G4 Ventilation – Third Edition.* **www.dbh.govt.nz**

17 Standards New Zealand (1990) *NZS 4303:1990 Ventilation for acceptable indoor air quality.* **www.standards.co.nz**

18 Standards Australia (2002) *AS 1668.2:2002 The use of mechanical ventilation and air-conditioning in buildings, Ventilation design for indoor-air contaminant control.* **www.infostore.saiglobal.com** *(Note: Although updated in 2012, this version is referenced in Clause G4)*

19 Standards New Zealand (2013) *AS/NZS 5601.1 Gas installations, General installations.* **www.standards.co.nz**

Transport Agency specification

The Building Code ventilation requirements are a legal minimum to safeguard health. However, if mechanical ventilation is installed so that windows can remain closed for noise mitigation, then the comfort of the occupants should also be considered. For comfort, people often open windows to achieve significantly higher airflows than the Building Code minima.

Ventilation and cooling systems are often specified in district plans as part of reverse sensitivity controls for houses near airports, ports, roads and railways. However, there is substantial variation between specifications, despite the systems all serving the same basic purpose in each case. The range of different specifications commonly found in district plans was reflected in the proposed Auckland Unitary Plan in 2013, where houses near airports, ports, road and rail had varying ventilation requirements. To ensure that residential homes receive fair and reasonable mechanical ventilation solutions, a review of these requirements was undertaken[20]. The review found that:

- The requirements of Clause G4 of the Building Code (Schedule 1 of the Building Regulations 1992) are not designed to provide thermal comfort. District plans that specify compliance with Clause G4 for ventilation systems as part of reverse sensitivity controls are unlikely to achieve the intended outcome. Occupants would be likely to experience hot/stuffy conditions at least in summer, and would probably open the windows which should remain closed to achieve appropriate indoor noise levels.
- Systems which seek to simulate cooling through provision of high air flow rates (up to 15 air changes per hour), have a number of significant drawbacks and will not always achieve the desired cooling effect. Issues with a high air flow rate ventilation only system include relatively high capital and maintenance costs, larger components, and higher levels of system noise to control.
- Provision of a ventilation system including cooling, such as from a reverse cycle heat pump, is likely to be the most effective way of achieving reasonable thermal comfort, commensurate with the effect that would be obtained by opening windows. However, in cooler regions such as the lower North Island and coastal and southern parts of the South Island, mechanical ventilation alone would be sufficient.

Where mechanical ventilation or cooling is provided as an alternative to opening windows it should be a genuine alternative such that occupants are not forced to choose between excess noise or hot/stuffy conditions. Prior to 2014, to achieve this outcome the Transport Agency generally sought either a high air flow rate or cooling, when ventilation systems were required as part of reverse sensitivity controls. As a result of the review described above, the following specifications are now recommended for ventilation and cooling systems installed as noise mitigation:

SPECIFICATION FOR VENTILATION AND COOLING SYSTEMS INSTALLED AS NOISE MITIGATION

- Ventilation must be provided to achieve the requirements of Clause G4 of the New Zealand Building Code. At the same time as meeting this minimum requirement, the sound of the system shall not exceed 30 dB $L_{Aeq(30s)}$ when measured 1 m away from any grille or diffuser.
- The occupant must be able to control the ventilation rate in increments up to a high air flow setting that provides at least 6 air changes per hour. At the same time as meeting this requirement, the sound of the system shall not exceed 35 dB $L_{Aeq(30s)}$ when measured 1 m away from any grille or diffuser.
- The system must provide cooling that is controllable by the occupant and can maintain the temperature at no greater than 25°C.
  [the above requirement can be omitted for cooler regions such as the lower North Island and coastal and southern parts of the South Island]

To achieve these requirements it is likely that the most common solution would be an in-ceiling ducted system with a reverse-cycle heat pump providing cooling (refer section 3.3).

In addition to the requirements detailed above, any ventilation and cooling system must comply with district plan requirements for noise emissions to neighbouring property. This may constrain the location of external equipment and air grilles, and/or require screening and attenuation.

Where practicable, this specification should be adopted for all Transport Agency projects where mechanical ventilation is used for noise mitigation.

20 Beca (2013) *New Zealand Transport Agency Building Acoustic Mitigation Case Study.* **www.acoustics.nzta.govt.nz**

3.2 NATURAL VENTILATION

Methods of natural ventilation include opening windows/doors and installing ventilation stacks and trickle vents. The rate of natural ventilation into a building is determined by:

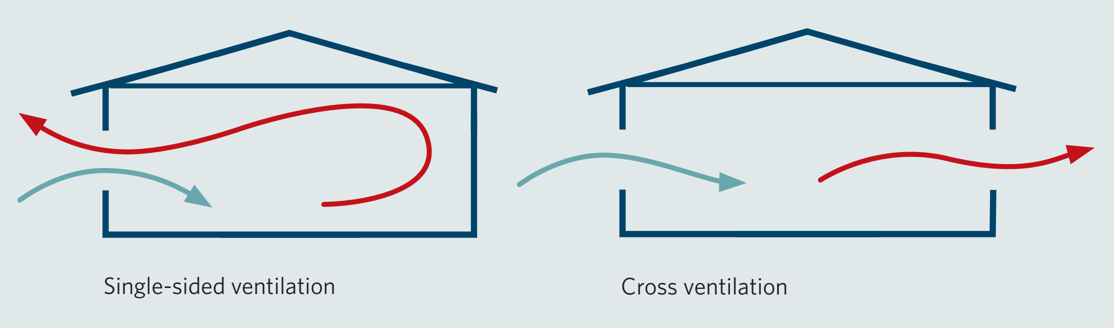
- pressure differentials between the external environment and the internal spaces
- pressure differentials between the windward and leeward side of a building
- thermal gradients in the local area
- the shape, size and orientation of the building and its openings.

The following discussion relates to natural ventilation primarily to comply with Clause G4. When considering acoustic treatment for road-traffic noise, higher ventilation rate settings are required as detailed in section 3.1, and therefore mechanical systems are likely to be required in addition to natural ventilation.

Openings in the building

When natural ventilation is provided by openings in the building such as windows/doors and construction gaps, for Clause G4 the total openable area should be at least 5% of the floor area. For a typical dwelling (such as shown below) with a floor area of 130 m^2, this equates to an openable area of 6.5 m^2. This could be provided by a 2.4 m high sliding door with a full horizontal travel of approximately 2.7 m. However, in practical terms this area of ventilation will need to be distributed around the building.

FIGURE 29: NATURAL VENTILATION OPENINGS



Trickle vents

Trickle vents are a method of providing an opening for ventilation. These are often linear slots built into window frames above the glass (figure 30). While uncommon in New Zealand, there are trickle vents available with integral noise attenuation.

The size of any trickle vent needs to comply with Clause G4, which includes a minimum area for trickle vents in any room, accounting for airflow constraints through the vents.

Passive stack effect ventilation

Passive stack ventilators use buoyancy effects to provide ventilation (figure 31). This method can only be used in kitchens, bathrooms, toilets and laundry spaces to provide air extraction.

Drain traps, thermal conductivity, extraction rate, ingress of external moisture and the effect on fire paths in the building must also be considered for passive stack ventilators. Fire paths are usually of concern when considering installation within kitchens as a method of extraction.

Passive stack ventilators and trickle ventilators cannot be used in conjunction with mechanical ventilation in dwellings, and cannot be used to provide a ventilation connection to other spaces.

FIGURE 30: TRICKLE VENTS

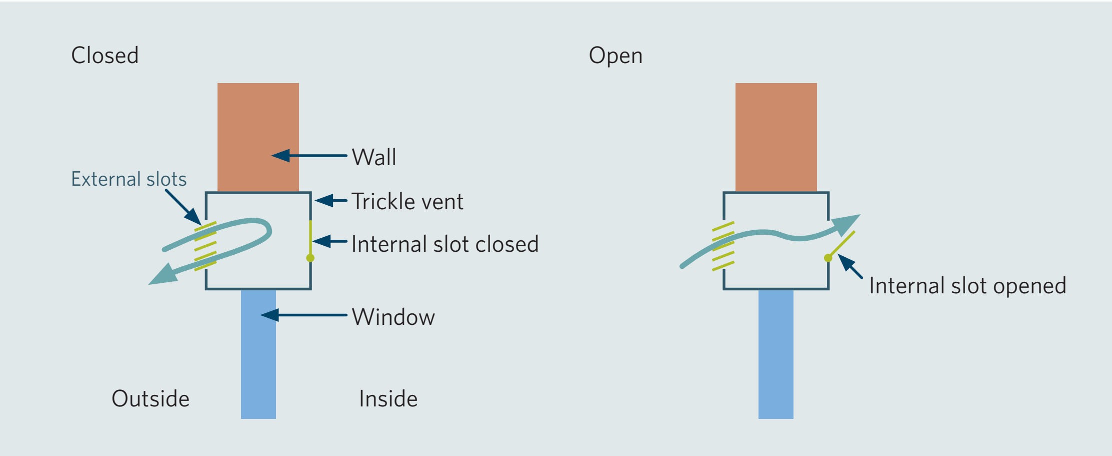
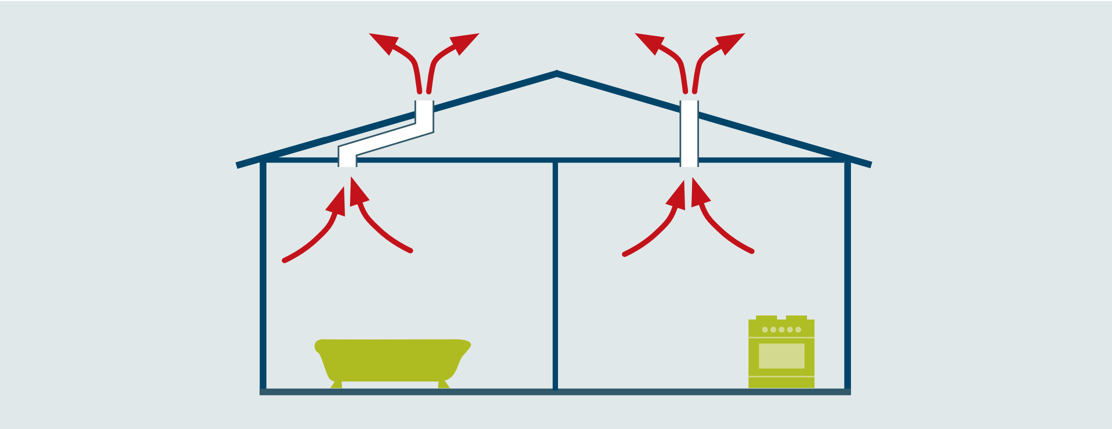


FIGURE 31: PASSIVE STACK VENTILATION



3.3 MECHANICAL VENTILATION

Mechanical supply with natural relief

A common system with a mechanical supply and natural relief is a classic heat transfer ventilation system, as shown in figure 32. The roof heats up throughout the day from the sun which increases the temperature of the air in the roof cavity. The warm air is then drawn through an air filter by the fan unit, and distributed through a network of ducts above the ceiling. However, research has concluded that this type of system should not be installed based on potential heating or cooling benefits[21].

These systems are also known as positive pressure ventilation systems. This means the supplied air slightly pressurises the building, pushing out the 'stale' air from occupied spaces through gaps such as windows and door frames.

21 University of Otago (2011) *Heating and cooling potential of roof space air: Implications for ventilation systems.* **www.eeca.govt.nz**

Mechanical exhaust with natural make-up

Examples of mechanical air exhaust with natural make-up are stove range-hoods for kitchens, and bathroom and toilet extract fans (figure 33). Air is extracted from a space and make-up air comes either from natural leakage through gaps or openings such as windows, or from devices such as trickle vents.

Mechanical exhaust systems only have local effects regarding the flow rate they are able to produce for equivalent fan sizes. This means that for a fixed size fan it is more effective to use the fan to push air into a space and exhaust air by displacement than it is to extract air with the fan and draw in natural make-up air.

FIGURE 32: HEAT TRANSFER VENTILATION SYSTEM

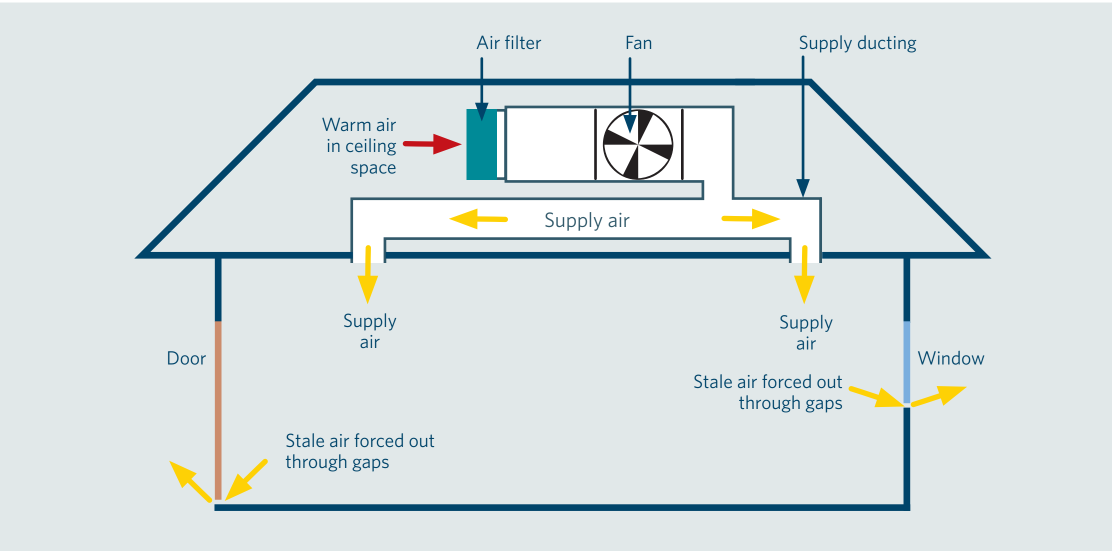
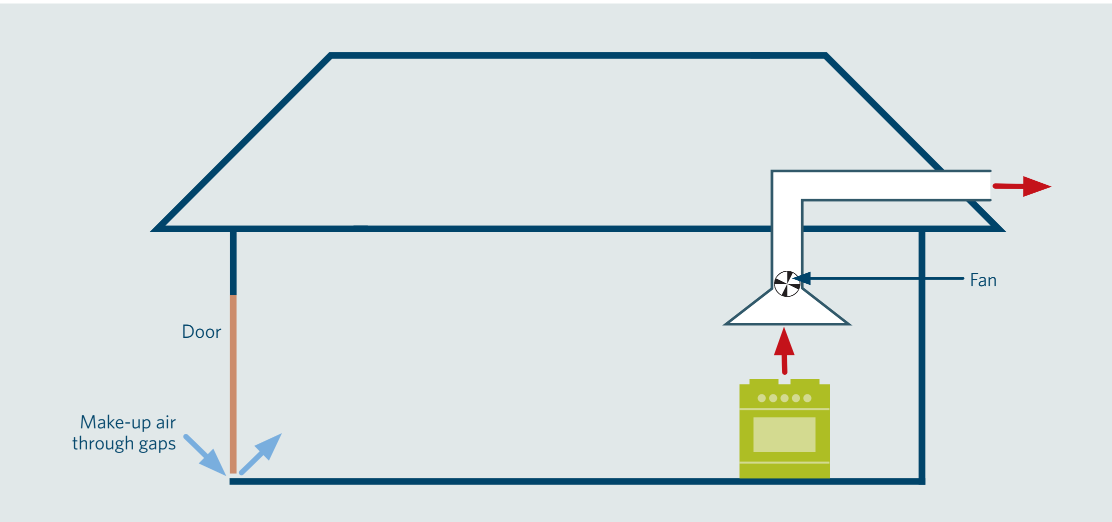


FIGURE 33: MECHANICAL EXHAUST FAN



Mechanical supply and exhaust

This is a purely mechanical system. Supply air is drawn in by a supply fan and exhaust air is extracted by an exhaust fan. The system can incorporate other components such as air filters and a heat exchanger, to form a 'heat recovery system' (figures 34 and 35). Air is distributed within the building by way of a network of ducts normally above the ceiling.

FIGURE 34: HEAT RECOVERY SYSTEM

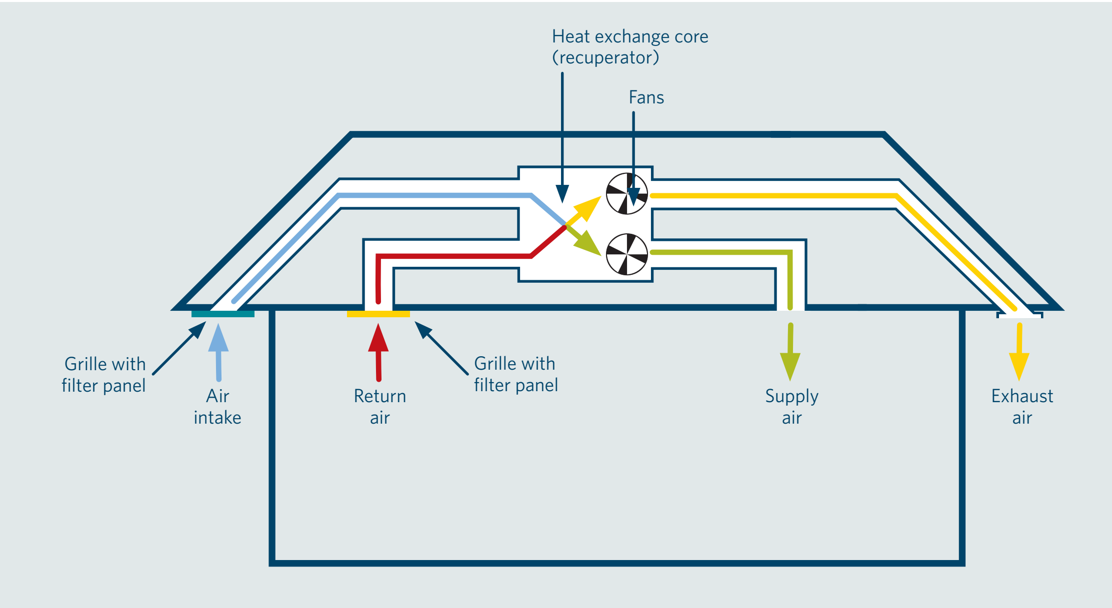


FIGURE 35: HEAT RECOVERY UNIT

Air conditioners and heat pumps

The ventilation systems discussed so far cannot fully control the temperature of the air supply to a building. The temperature of the supply air is governed by the conditions outside and to change them would require additional control devices that require extra energy or power. Climate control systems have a higher degree of control over the air system of a building. Examples include air conditioners for cooling and inverter heat pumps.

Air conditioning systems include a thermostat to actively control the temperature of the air being supplied to a building. The system will in most cases provide cooling, dehumidification and air filtration.

Heating can be achieved by adding a heating element or hot water coils. Available systems range from a basic window installed unit that conditions outdoor air prior to internal supply, to systems that use split components and ducting to provide greater cooling capacity.

A heat pump is a compact re-circulating air conditioner which can operate in both a cooling and heating capacity. These systems are mechanically comparable to air conditioning systems but with the advantage of only occupying a fraction of the space. Heat pumps do not introduce outdoor air into the space, which must be separately provided.

FIGURE 36: DUCTED AIR CONDITIONING SYSTEM

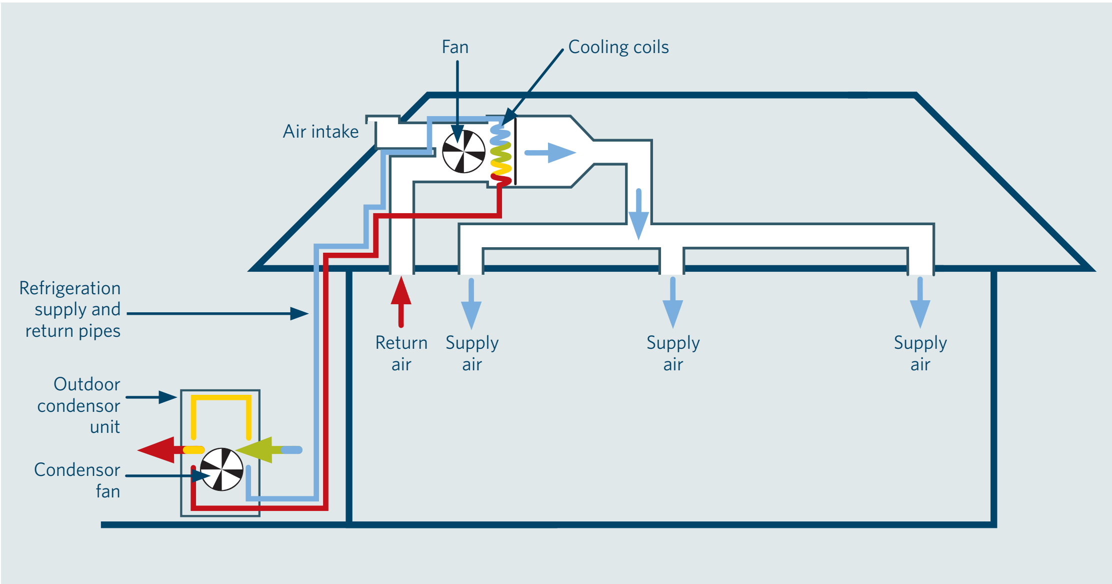


FIGURE 37: OUTDOOR AND INDOOR UNITS OF A HEAT PUMP SYSTEM

3.4 SYSTEM SELECTION

This section provides brief summary of the ventilation systems discussed in sections 3.2 and 3.3. Where a ventilation system is being installed by the Transport Agency as acoustic treatment it must provide heating and cooling functions, as well as an outdoor air supply, as its purpose is to allow windows to be closed. In most cases ducted air conditioning is the only practical system that meets the Transport Agency requirements. For completeness a comparison summarising all systems is provided in table 5. System types that do not meet the Transport Agency specification are shown in grey in table 5.

TABLE 5: SUMMARY SYSTEM COMPARISON

System	Ducted air conditioning	Trickle vents	Heat recovery system	Passive stack	Heat transfer system	Heat pump
Ventilation type	Climate control	Natural	Mechanical	Natural	Mechanical	Climate control
Outdoor air supply	•	•	•	(indirect)		
Heating	•		•		•	•
Cooling	•					•
Humidity control	•					•
Ventilation rate control	•		•		•	•
Installation 1: simple 5: complex	5	2	4	2	3	3
Maintenance 1: minimal 5: involved	5	1	4	2	3	3
Indicative cost (2011)	$10000 per household	$1000 per vent	$5000 per household	$2000 per stack	$4000 per household	$3000 per heat pump

Notes

A household is assumed to be a single-storey three-bedroom dwelling.

The costs are indicative of hardware only and do not include labour costs.

CASE STUDY – SH20 MT ROSKILL, AUCKLAND (2005–2009)

The SH20 Mt Roskill Extension is a key part of the Auckland Western Ring Route. It is a new four-lane, four kilometre long motorway. SH20 will be extended again when the Waterview Connection is undertaken, but in the interim the Mt Roskill Extension ends at a local road, Maioro Street. To accommodate motorists accessing the motorway extension Maioro Street was widened to four lanes as part of the project. This case study relates to houses on Maioro Street.

A designation condition required the Transport Agency to comply with the noise criteria in the old Transit Guidelines[22]. A noise assessment showed that in most cases structural mitigation (low-noise road surfaces and noise barriers) would be sufficient. However, these measures were impracticable for a number of dwellings in Maioro Street. For example, the barrier height needed at two-storey buildings often proved prohibitive. Also, in some places the most effective barrier location was outside the designation but residents did not want the barrier on their properties, and even within the designation the Auckland Council did not want barriers for which it would have ongoing responsibility, given that this is a local road. Building-modification was therefore recommended as the noise mitigation solution for approximately 35 dwellings.

It was determined that closing windows would provide sufficient noise reduction, so the building-modification required was the provision of mechanical ventilation. A heat recovery system was selected as it provided residents with additional benefits as well as achieving the acoustic objectives. The main design criteria were as follows.

22 Transit New Zealand (1999) *Guidelines for the management of road traffic noise – State highway improvements. Planning Policy Manual SP/M001, Appendix 6.* **www.acoustics.nzta.govt.nz**

FIGURE 38: SH20 MT ROSKILL EXTENSION

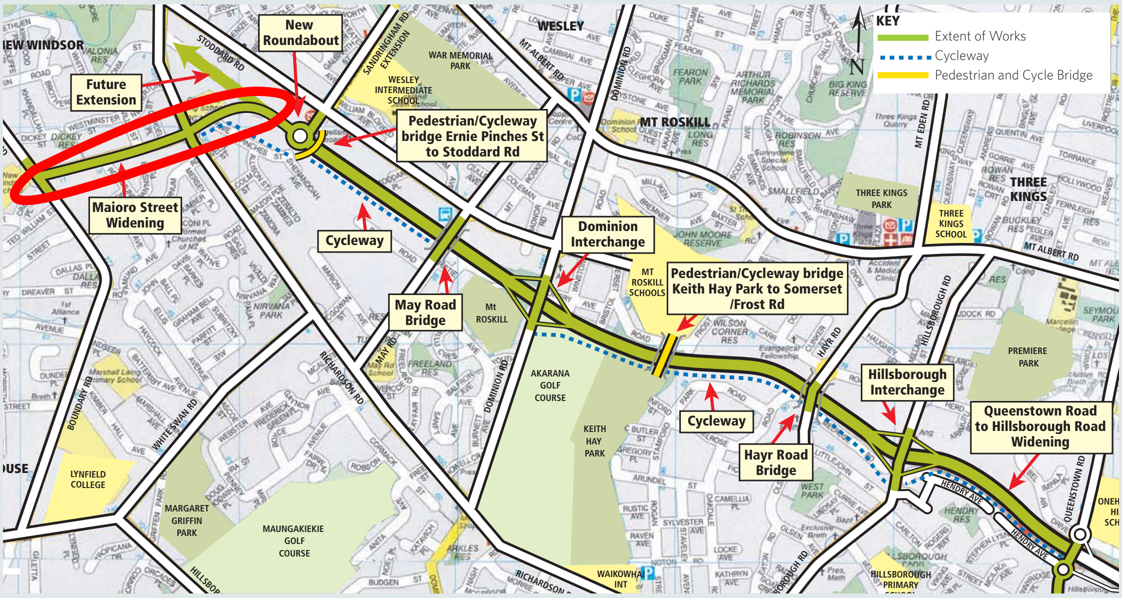


FIGURE 39: HOUSES REQUIRING ACOUSTIC TREATMENT

Building Code requirements:

- Provide minimum required air changes per hour for relevant building type (NZS 4303).
- Allow for air extraction in bathroom (NZS 4303).

Allow for additional supply air to offset combustion appliances that may be installed in building (NZS 5261, which has subsequently been superseded by AS/NZS 5601.1[19]).

Fan noise criteria:

- Habitable rooms (internal): 35 dB L_{Aeq}
- Site boundary (external): Auckland City Council District Plan – Isthmus section 40 dB L_{A10}

Auckland outdoor temperature:

- 27°C summer dry bulb
- 22°C summer wet bulb
- 3°C winter dry bulb.

FIGURE 40: SCHEMATIC DRAWING OF SH20 VENTILATION SYSTEM

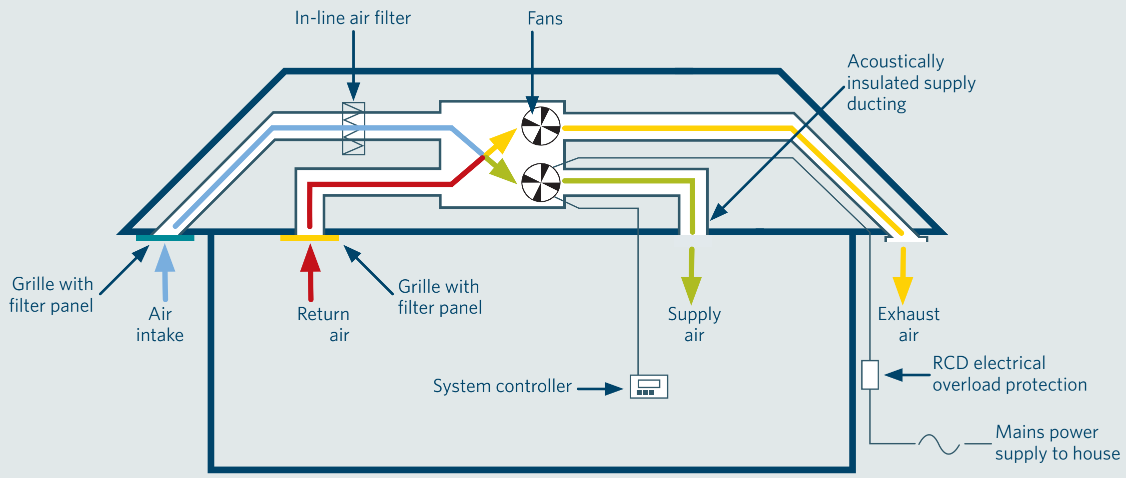
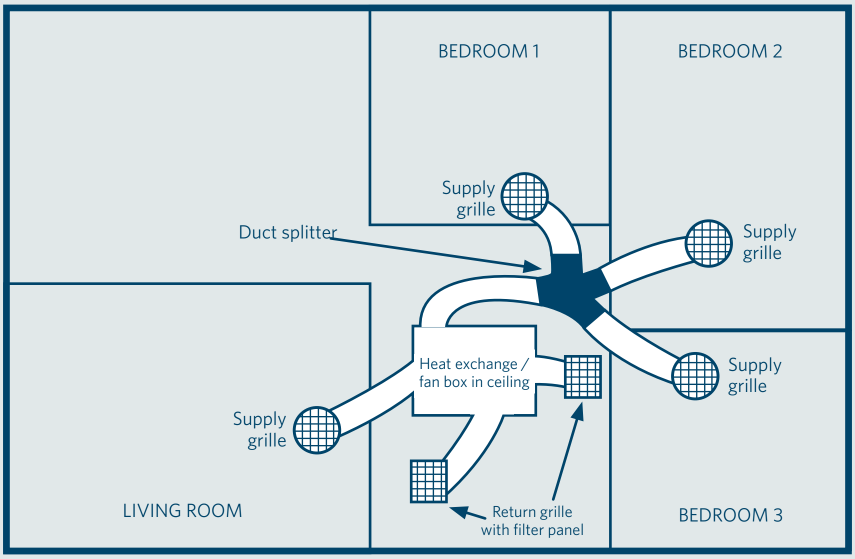


FIGURE 41: TYPICAL PLAN OF SH20 VENTILATION SYSTEM



System components

- An **access hatch** was required to the ceiling void for the fan unit to be installed and allow for future maintenance. Smaller fan units will generally fit through a standard 600 mm^2 hatch.
- 250 mm^2 external **intake and exhaust grilles** were installed into building soffits. The hinged intake grille could accommodate a filter panel to pre-filter the outdoor supply air. When access restrictions made it impracticable to install an intake filter, an in-line filter box was used within the intake air duct. The unit has two filters which are part of the main fan and heat exchanger housing. These can be removed for servicing.
- The **supply air grilles** are easily adjusted to alter the airflow to a particular space. This is achieved by screwing or unscrewing the central part of the air 'diffuser' which opens or closes the air path.
- **Return air grilles** are hinged egg crate type items with integral filter panels. This is necessary to prevent particulates in the return air entering the extract fan of the main unit.
- The **fan** can run at nine speeds, which can accommodate up to four different house floor areas. The correct fan speed is set for the required air changes per hour (ACH) based on the house's floor area. As an example, fan speed 5 is used to provide 0.35 ACH at floor area setting two (210 m^2 – 240 m^2).
- The **heat exchanger** uses a polymer material core. This type of core requires a pipe to be installed to allow drainage of any condensation that forms on it. There are 'paper' type heat exchanger cores available on the market, which can draw out any condensation formed in the system. However, there has been limited testing of these cores in New Zealand and they are therefore not considered an appropriate solution at this stage.
- Ducting used for the project is thermally insulted (R1.0). Ducts are 200 mm diameter for the intake, supply and exhaust and 150 mm diameter for the return. The ductwork also incorporated acoustic attenuation to limit sound from the fan along ductwork to the habitable spaces.
- The **touch screen control** for the project has nine selectable fan speeds, room temperature and humidity sensor, ceiling temperature sensor, occupant adjustable comfort settings, fan-boost mode, maintenance schedule and energy savings meter. The system also allows occupants to select for incoming outdoor air to bypass the heat exchanger. This is useful in summer when the outdoor temperature is higher than the temperature desired inside.

FIGURE 42: INTAKE AND EXHAUST AIR GRILLES

FIGURE 43: DUCTWORK PROVIDING ACOUSTIC ATTENUATION

FIGURE 44: TOUCH SCREEN CONTROL

System maintenance

Maintenance is the responsibility of the owner/occupant of the building. The users' manual recommends cleaning panel filters every six months and in-line filters once annually. Owners and occupants were informed by the contractor performing the installations and the Transport Agency about their responsibility for maintaining their building ventilation system. The warranty period for the system is 12 months.

Lessons learnt

The SH20 Mt Roskill Extension project was notable for the extensive use of building-modification mitigation in the form of mechanical ventilation systems. In installing these systems a number of areas were identified where the work could be refined for future projects:

- After installation some residents reported air indoors being warmer than desirable, particularly in upstairs rooms. This occurred with the system operating with the summer bypass, so the temperatures were being determined solely by the outdoor conditions, which happened to be hotter than normal (summer 2010/2011). When using opening windows the feeling of air movement can alter the perception of temperature, compared to the ventilation system which is designed not to cause such draughts. Before the Transport Agency installs ventilation systems residents should be made aware that they do not provide cooling and that air movement will not be felt.
- Some residents commented that they expected the works to result in greater reductions to road-traffic noise levels. Noise commissioning measurements were made to verify that the fan noise was within the limits shown on page 30. Where residents were present during these measurements they generally appreciated seeing the process followed, which aided understanding of the resulting road-traffic noise levels. During initial consultation with residents it should be made clear that road-traffic noise will still be clearly audible, but at a reasonable level.
- The ventilation system was based on a generic design, which worked effectively for the majority of houses. Adaptation of the design is required for cases such as larger houses or houses with flat roofs. When using a generic design it is important that special cases requiring adaptations are identified and addressed during the design stage.
- During installation in some houses the contractor made minor adaptations which were not appropriate, including some not complying with the Building Code. These issues were identified during commissioning and rectified. It is important that regular communication is maintained between the contractor and the Transport Agency designer, so that such adaptations are discussed before being implemented. The Transport Agency should conduct detailed commissioning of all systems.
- A sophisticated digital controller was installed which provided useful functionality for commissioning the system and ongoing control by residents. However, while a comprehensive instruction manual was provided, some residents found the three level menu system and options confusing, resulting in selection of inappropriate settings. For future projects consideration should be given to simple physical switches/dials/sliders, or a controller that provides an equivalent interface on the initial menu screen, clearly separated from configuration settings.

4

PLANNING AND PROCUREMENT

4.1 STATUTORY AND LEGAL

This section provides a summary of the statutory approvals required and legal issues for the Transport Agency to install acoustic treatment.

Building Act

All acoustic treatment installed by the Transport Agency must comply with the Building Act. Specific Building Code requirements for ventilation systems are summarised in section 3.1 of this guide, and any changes to the ventilation of a building, such as the installation of mechanical ventilation, will require building consent from the territorial authority. As this is the most common form of building-modification noise mitigation measure for road-traffic noise, building consent will usually be required when the Transport Agency is treating a house. Other works that might be conducted for noise mitigation such as replacement windows would probably not require building consent[23]. Replacement wall linings might require building consent depending on the extent of alterations. The territorial authority should be consulted in all instances.

The building consent process is described in: *www.dbh.govt.nz/blc-building-consentinspect-process*

23 Ministry of Business, Innovation & Employment (2014) *Guidance: Building work that does not require a building consent, Building Act 2004. Third Edition.* **www.dbh.govt.nz**

Resource Management Act

RESOURCE CONSENT

In addition to building consent, resource consent may be required from the territorial authority for some acoustic treatment. Works can alter the external appearance of a building, such as introduction of new ventilation inlets/outlets and changes to windows and wall cladding. Although it is unlikely in the majority of circumstances that changes to the external appearance will be significant enough to require resource consent, the applicable district plan should be reviewed.

The resource consent process is described in: *www.mfe.govt.nz/rma/public/consent-apply/index.html*

DESIGNATION CONDITIONS

The need for acoustic treatment will often form part of the designation conditions for a Transport Agency project. The structure and details of the designation conditions may vary, although the Transport Agency has prepared model conditions that are likely to form the basis of requirements in most instances. These are available on the Highways Information Portal, hip.nzta.govt.nz. Figure 45 shows the process defined by the model conditions. Designation conditions with alternative requirements take precedence, but if full details of the process are not specified then figure 45 should be followed. The Transport Agency's legal team should be consulted where a designation specifies noise limits and building modification is required.

Acoustic treatment requires works in buildings owned by third parties. The process shown in figure 45 provides a formal framework, which avoids the Transport Agency having noise mitigation obligations it cannot achieve because of the actions or inactions of a third-party. In all cases when acoustic treatment is to be installed the focus should be on effective communication with the building owners and not just these procedural minima (refer to section 4.3). In many cases the process could be significantly quicker than the maximum timeframes indicated.

Heritage New Zealand Pouhere Taonga Act

If a building and/or its site dates pre-1900 it is an archaeological site under the Heritage New Zealand Pouhere Taonga Act 2014, and an authority from Heritage New Zealand may be required prior to carrying out any modifications. Archaeological sites are registered in the New Zealand Archaeological Association's database. If a building and its site are post-1900 it may still have heritage significance and will then be subject to the Resource Management Act (Section 6(f)), which provides for the protection of historical heritage from inappropriate subdivision, use and development. A consent from the territorial authority may be required, particularly if the site is scheduled in the district plan and/or included in Heritage New Zealand's register. This is also the case for sites that have been identified as having heritage value in a specialist assessment. Under any of these scenarios, Heritage New Zealand and territorial authority heritage specialists should be contacted early to confirm statutory and technical requirements.

FIGURE 45: ACOUSTIC TREATMENT PROCESS (OUTLINED BY MODEL CONDITIONS)

Step	TIMEFRAME	COMMENTS
The Transport Agency identifies 'Category C Buildings' (Refer to section 2.9)	Prior to construction. This will usually occur as part of the Assessment of Environmental Effects (AEE) for 'build-now' designations.	Requires an acoustics specialist.
The Transport Agency writes to building owner requesting entry	Prior to construction.	No further action is required by the Transport Agency if the building owner cannot be found prior to completion of construction. The Transport Agency's written request should include an entry agreement for the site inspection.
Building owner to agree to entry to the building	Within 12 months of the request for entry.	No further action is required by the Transport Agency if the building owner does not respond, or does not allow entry to the building. To proceed, the building owner must sign the entry agreement.
The Transport Agency visits building and assesses existing building performance		Requires an acoustics specialist. No further action is required by the Transport Agency if entry to the building cannot be gained (such as entry denied by a tenant).
The Transport Agency advises building owner of mitigation option(s)	Within six months of assessment.	No further action is required by the Transport Agency if the building owner cannot be found prior to completion of construction. The Transport Agency provides an entry agreement for the installation.
Building owner advises whether mitigation offer is accepted and which option is preferred	Within three months of advice of options from the Transport Agency.	No further action is required by the Transport Agency if the building owner does not respond, or does not accept the mitigation options. To proceed, the building owner must sign the entry agreement.
Mitigation implemented	A reasonable and practical timeframe agreed between the Transport Agency and the building owner. Where practicable, the treatment should be installed prior to construction works in the area.	The Transport Agency commissions the works and then the building owner signs the form in the entry agreement to confirm completion.

4.2 ENTRY AGREEMENTS

The process of designing and installing acoustic treatment requires legally binding agreements to cover:

- the site inspection required to design the acoustic treatment
- the installation of the acoustic treatment (where managed by the Transport Agency)

'Entry agreements' are typically between the Transport Agency and the building owner but may also be between the Transport Agency's contractor and the building owner, depending on where the liability is to be held. A nominal payment is required by the Transport Agency in each agreement. Templates for these agreements are provided on the Transport Noise website (www.acoustics.nzta.govt.nz).

For properties that have separate occupiers, the building owner may need to arrange additional agreements with them, depending on the terms of their leases or licences to occupy.

The Transport Agency's legal team should be consulted on any queries relating to these agreements, particularly if there are unusual designation conditions.

Copies of all completed agreements should be saved in the Transport Agency's property database.

SITE INSPECTION

An entry agreement is required for the site inspection to arrange legal access to the property. This agreement is required even for non-invasive works such as noise measurements and visual inspections. The agreement includes:

- identification of the building
- scope of the inspection and noise assessment
- dates, times and the prior notice period of the inspection.

INSTALLATION

A second entry agreement is required for the installation of the acoustic treatment and is similar to the site inspection agreement. In this case, an explicit description of the acoustic treatment to be installed is included. Under the agreement the Transport Agency takes responsibility for commissioning the works (such as airflow and noise from ventilation systems) and for ensuring any required building consent inspections occur. The agreement includes a form to be signed by the property owner following commissioning to acknowledge that the works specified have been completed.

ALTERNATIVE INSTALLATION

In some cases the Transport Agency may agree to provide funding for a building owner to manage the works directly. In this instance an 'encumbrance' is used to make requirements clear relating to the ongoing ownership and maintenance of the acoustic treatment. Effectively this document sets out that the installed treatment belongs to the property owner, along with maintenance responsibilities, and removes future obligations from the Transport Agency. Additionally, the owner agrees to accept the increase in road-traffic noise if the treatment is not maintained, removed, or switched off in the case of a ventilation system.

The encumbrance is to be agreed with the property owner and registered with Land Information New Zealand when payment is made by the Transport Agency for the works. The encumbrance will then appear when anyone searches for information on the property title.

Enhancements

The Transport Agency should only fund works to the extent necessary to achieve the specified noise criteria. In some cases this will only require treatment of certain rooms in a building, or even only certain facades of a particular room. However, in some cases, to avoid creating visual discontinuities for example, the works funded by the Transport Agency might require treatment of walls beyond the bare minimum required just for noise mitigation. In addition to any such extension to the works, a building owner might wish to enhance the mitigation offered, such as:

- addition of cooling or heating coils to a ventilation system, beyond those needed to meet the specification
- ventilation of additional habitable spaces beyond those required to be ventilated for noise mitigation
- replacement glazing of all windows and not just those facing the road
- replacement of old timber window frames with aluminium joinery.

In these cases, if the enhanced works are directly connected to the mitigation offered, then the Transport Agency should try to include them, at the building owner's expense. Any such arrangement should be agreed on an individual basis and included in the formal mitigation agreement.

4.3 STAKEHOLDER ENGAGEMENT

The primary purpose of stakeholder engagement is to achieve a better outcome. The Transport Agency cannot undertake any acoustic treatment without the express permission of the building owner. Therefore, unlike other operations, some level of stakeholder engagement is automatic in this instance. However, the acceptance of the acoustic treatment by the building owner and their satisfaction with the outcome could be significantly affected by the timing and effectiveness of engagement throughout the process.

The Transport Agency's *Public engagement policy and guidelines*[24] provides guidance for deciding when and how to engage the public. When applying the public engagement policy and guidelines users should use professional judgement and take into account local circumstances and context. The guidelines are advisory and are provided as an aid to planning and decision making for projects.

Stages of stakeholder engagement with building owners where acoustic treatment is an option should typically include discussion of:

- the project intent, road design and assessment process, predicted noise levels and criteria, as well as any possible noise mitigation
- issues relating to heritage buildings, disturbance of interior decoration, both the internal and external appearance of windows, any changes to the appearance of the external facade and whether consents will be required
- pros and cons of different acoustic treatment options, including both installation and ongoing use/maintenance
- the legal agreements, the legal effects, rights and obligations, and the choice of property owners to seek independent legal advice
- any enhancements to the mitigation desired by the building owner
- options for the Transport Agency managing and contracting the works, if appropriate, or the building owner managing and contracting the works
- timing of the works and potential disruption
- progress of works and any delays or alterations
- whether once the works are completed the treatment is in accordance with the mitigation agreement.

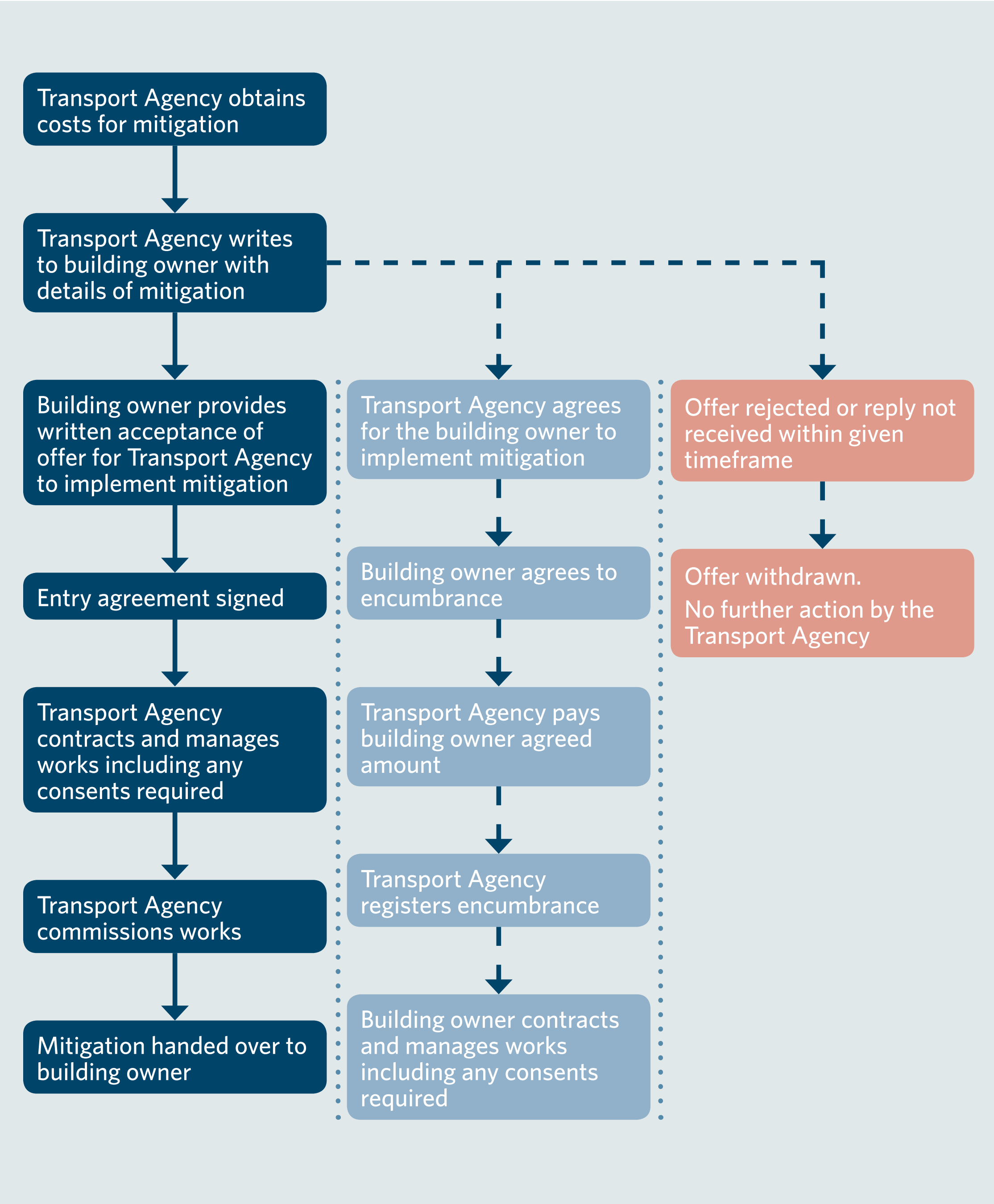
The Transport Agency should provide details for a person that the building owner can contact regarding the proposed works at any time throughout this process. Contact details should also be provided for other parties, such as anyone visiting/inspecting the building and the contractors who will be on site installing the acoustic treatment.

24 NZ Transport Agency (2008) *Public engagement manual part 1: Public engagement policy and guidelines, working draft.* **www.nzta.govt.nz**

4.4 IMPLEMENTATION

Once the building owner has reviewed and accepted the noise mitigation offer and has advised the Transport Agency of their preferred option then the implementation phase of the works can proceed. Normally the Transport Agency undertakes the work following the implementation process in figure 46. This process flows on from the acoustics treatment process outlined in figure 45. Actions in this process attributed to the Transport Agency will generally be carried out by professional advisors. Alternatively, in some instances the Transport Agency may offer the building owner the option to manage the works themselves. Figure 46 shows the process for this alternative implementation, and also the steps if offer is rejected or not accepted in the required timeframe.

FIGURE 46: IMPLEMENTATION PROCESS

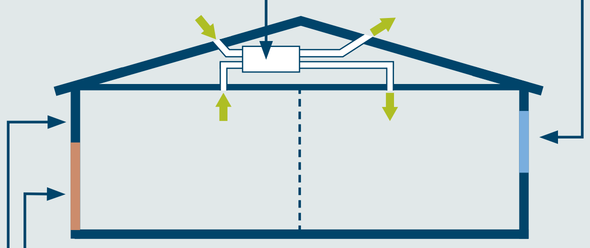


4.5 COSTS

Indicative costs (2011) for supply and installation of different types of acoustic treatment of residential buildings are shown in the tables below (figure 47). These costs should be used as a guide only, as they will vary significantly between different buildings.

Undertaking building modification to new homes is cheaper in comparison to retro-fitting existing homes. The following case study details the costs involved for building modification to new homes affected by traffic noise in order to achieve internal noise levels that meet NZS 6806.

FIGURE 47: INDICATIVE COSTS (2011) FOR ACOUSTIC TREATMENT, EXCLUDING GST



Ventilation	Indicative cost
Heat recovery system	$10,000 per unit
Air conditioning system (ducted)	$15,000 per unit

Glazing	Indicative cost
4 mm or 6 mm	$70 per m^2
10 mm	$115 per m^2
6 mm laminate	$145 per m^2
10 mm laminate	$250 per m^2
4 mm / 12 mm / 4 mm double	$200 per m^2
4 mm / 12 mm / 6 mm double	$240 per m^2
6 mm / 12 mm / 6 mm double	$280 per m^2
4 mm / 100 mm / 6 mm or 4 mm / 200 mm / 6 mm secondary	$500 per m^2

Does not include costs of new frames.

Door	Indicative cost
44 mm solid core single, with seals	$700 per door
54 mm solid core single, with seals	$750 per door

External wall	Indicative cost
Add 13 mm dense plasterboard to internal wall lining	$35 per m^2
Replace internal wall lining with two layers of 13 mm dense plasterboard and 75 mm fibreglass in cavity	$90 per m^2
Replace internal wall lining with two layers of 13 mm dense plasterboard fixed back to stud on acoustic clips and rail	$175 per m^2
Replace internal wall lining with two layers of 13 mm dense plasterboard on separate staggered stud with 75 mm fibreglass within overall cavity width of 150 mm	$125 per m^2
Remove and replace weatherboard on top of one layer of 9 mm compressed fibre cement board with 75 mm fibreglass in cavity	$235 per m^2

CASE STUDY – BUILDING ACOUSTIC MITIGATION COSTS

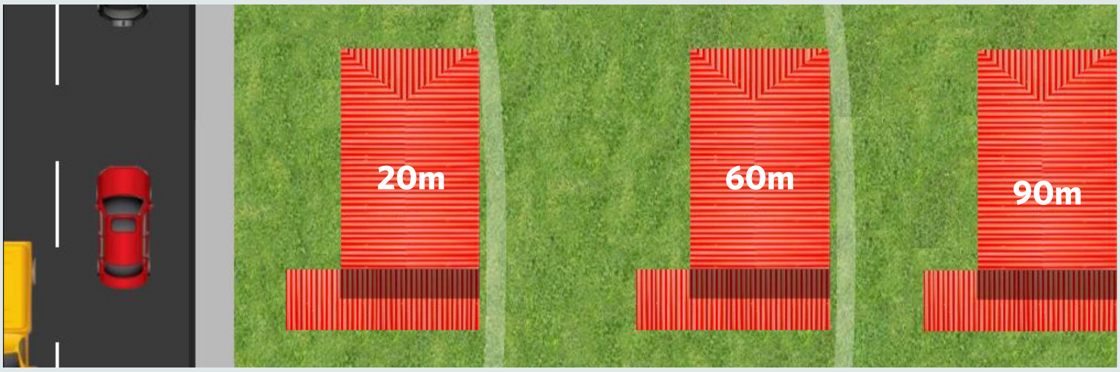
The Transport Agency has recently undertaken a study to outline and quantify what building modifications may be required to new homes affected by traffic noise. Building modification may be required in order to achieve internal noise levels that meet NZS 6806. The Transport Agency's reverse sensitivity guidance[03] recommends that rules should be included in District Plans that require new and altered buildings near roads to be designed to achieve road-traffic noise levels that will not cause sleep disturbance or annoyance. The case study has been undertaken to assist the Transport Agency and Territorial Authorities in estimating typical costs for such building modifications.

Methodology

A traffic noise level was determined which provided a baseline noise level for an acoustic mitigation solution. Three noise exposure locations were assessed based on the distance of the building from the noise source - 20m, 60m and 90m (figure 48):

- At 20m, the traffic noise incident on the façade of the house is 70dB $L_{Aeq\ (24h)}$
- At 60m, the traffic noise incident on the façade of the house is 66dB $L_{Aeq\ (24h)}$
- At 90m, the traffic noise incident on the façade of the house is 64dB $L_{Aeq\ (24h)}$.

FIGURE 48: NOISE EXPOSURE LOCATIONS



To produce these traffic noise levels with a speed of 100 km/h and 10% heavy goods vehicles, the annual average daily traffic (AADT) and road surfaces would be (other combinations could also result in the same noise levels):

- AADT 9,000 on Grade 3/5 chipseal
- AADT 30,000 on open graded porous asphalt OGPA-14, with 20% voids
- The main living room and most bedrooms face the road; this is the worst case scenario in regards to building orientation
- There is no screening by other buildings, terrain or fences (noise levels and treatment would be reduced with screening).

Two notional building designs were selected for the study. The building designs were sought from a large house building company to be representative of typical homes being constructed in New Zealand in 2013. The designs are for a typical single storey home (three bedroom, 175 m²) and a typical double storey home (four bedroom, 225 m²). These are shown in figures 49 and 50 respectively.

An assessment of the two building designs was undertaken at each of the three noise exposures locations. A sound insulation design was then provided for each location in order to achieve internal noise levels that meet NZS 6806. A cost assessment was undertaken for each design solution. The costs determined were the additional costs of including the mitigation as part of a new build house in 2013, and are not costs for retrofitting mitigation.

FIGURE 49: VH 175 SINGLE-STOREY HOME

FIGURE 50: BH 225 TWO-STOREY HOME

VENTILATION

The acoustic design is contingent on all doors and windows being closed in order to be effective. Therefore as part of the overall acoustic mitigation solution, mechanical ventilation was required to maintain habitable indoor conditions. Mechanical ventilation systems must comply with the New Zealand Building Code and also allow for sufficient air circulation to cool the home during peak summer months.

The ventilation rates used within this case study were based upon compliance with the NZ Building Code and the Manukau City District Plan. Updated specifications are now recommended in section 3.1 of this Guide.

A heat recovery ventilation system was used as a benchmark for the two building designs. Two different systems were investigated and have been designed to accommodate the required ventilation rates:

1. System 1 – Heat Recovery System (2-5 ACH) + Heat Pump
2. System 2 – Heat Recovery System (15 ACH).

System 1 is capable of providing ventilation rates at 2 to 5 ACH. This system was supplemented by a heat pump in order to provide sufficient cooling for the principle living area during peak summer temperatures.

System 2 is capable of providing ventilation rates at 15 ACH in the principle living area, this airflow is enough to sufficiently cool during peak summer temperatures and therefore did not require a heat pump.

ACOUSTIC MITIGATION

The closer the house is to the road, the higher the noise, and as a result a greater engineering effort is required. The following mitigation strategies were potentially implemented, though their use was dependent upon the distance from the road:

- Additional interior plasterboard lining
- Increased insulation rating for glazing units
- Additional wall / ceiling insulation.

The costs associated with these design changes are covered in the following section.

Results

MECHANICAL VENTILATION COSTS

Table 6 outlines the costs associated with the two different ventilation systems. With the additional cost of the heat pump, system 1 is significantly more expensive than system 2.

TABLE 6: MECHANICAL VENTILATION COSTS (2013)

SYSTEM	SINGLE STOREY	DOUBLE STOREY
1. Heat Recovery System (2 ac / hr) + Heat Pump	$7,850	$11,250
2. Heat Recovery System (15 ac / hr)	$5,900	$5,250

CONSTRUCTION COSTS

The base prices for the single storey and double storey houses are $235,000 and $332,000 respectively (2013). The total costs shown in table 7 are additions to the base price as a result of the acoustic mitigation designs. Mechanical ventilation costs have been included and for the purpose of the exercise; the lowest cost option (system 2) has been applied.

The findings show that as the distance from the road increases (and noise levels decrease), the costs of acoustic design also decreases. This is illustrated in table 7 which shows that at 20 m the percentage of the acoustic design costs against the total costs (base build + acoustic design costs) is 8-9%, this decreases to 4-5% at 60 m and 2-3% at 90 m.

Lessons learnt

- The additional use of a heat pump (in conjunction with a heat recovery system) to provide cooling, significantly increases the costs for mechanical ventilation.
- As distance from the road increases (and noise levels decrease), the costs of acoustic design also decreases.

TABLE 7: COST OF ACOUSTIC MITIGATION AS A % OF TOTAL COSTS

HOUSE	DISTANCE FROM NOISE SOURCE					
	20M		60M		90M	
	TOTAL COST	ACOUSTIC DESIGN AS PERCENTAGE OF TOTAL COST	TOTAL COST	ACOUSTIC DESIGN AS PERCENTAGE OF TOTAL COST	TOTAL COST	ACOUSTIC DESIGN AS PERCENTAGE OF TOTAL COST
Single Storey (base price $235,000)	$256,900	9%	$246,900	5%	$242,900	3%
Double Storey (base price $332,000)	$359,250	8%	$344,250	4%	$339,250	2%

4.6 SPECIFICATION

Specification requirements will vary between projects. The following provides guidance on specific requirements relating to acoustic treatment that may be appropriate in a specification, together with standard building work provisions.

Mechanical ventilation

As detailed in section 3.1, requirements should include the following:

- Ventilation must be provided to achieve the requirements of Clause G4 of the New Zealand Building Code. At the same time as meeting this minimum requirement, the sound of the system shall not exceed 30 dB $L_{Aeq(30s)}$ when measured 1 m away from any grille or diffuser.
- The occupant must be able to control the ventilation rate in increments up to a high air flow setting that provides at least 6 air changes per hour. At the same time as meeting this requirement, the sound of the system shall not exceed 35 dB $L_{Aeq(30s)}$ when measured 1 m away from any grille or diffuser.
- The system must provide cooling that is controllable by the occupant and can maintain the temperature at no greater than 25°C. [the above requirement can be omitted for cooler regions such as the lower North Island and coastal and southern parts of the South Island]

Other general requirements:

- Printed operating and maintenance instructions shall be provided to the building owner
- The system warranty shall be for at least 12 months.

Further requirements will depend on the system type selected. The case study in section 3 provides considerations related to components in a heat recovery system, which may require specification.

Glazing

The appropriate glazing configuration should be determined by an acoustics specialist to achieve the NZS 6806 Category C criterion of 40 dB $L_{Aeq(24h)}$. The performance of the glazing should then be specified directly rather than on the basis of a noise criterion inside spaces. For example, the specification could include the following:

- A laboratory test certificate in accordance with ISO 10140-2:2010 shall be provided to demonstrate that the glazing achieves the sound reduction indices (R). Refer table 8.
- The window frames and seals shall be selected to maintain the specified sound insulation performance of the glazing.
- All opening windows shall have effective acoustic compression seals, which shall be held evenly compressed when the window is closed.

For secondary glazing the specification should include the following:

- The secondary window shall be installed in a separate frame to the primary window, with no direct connections between the two frames.
- The reveals between the primary and secondary windows shall be lined with an acoustically absorbent material having at least absorption class C in accordance with ISO 11654:1997.
- Opening sections of the secondary window shall be aligned with openings in the primary window.

TABLE 8: GLAZING SOUND REDUCTION INDICES

Octave band	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
Minimum sound reduction index (R)	[X] dB	[X] dB	[X] dB	[X] dB	[X] dB	[X] dB
Example – 10 mm glass	26 dB	27 dB	34 dB	35 dB	36 dB	44 dB

Doors

As for windows, the appropriate door specification should be determined by an acoustics specialist to achieve the internal noise criterion. In this instance it may be appropriate either to specify the doorset acoustic performance for high performance doors (> 30 dB R_W) or just to specify the doorset construction for standard doors (M 30 dB R_W). For high performance doors the specification could include:

- The doorset shall be supplied and installed as a complete door leaf and frame assembly with all glazed sections, door furniture and seals factory fitted.
- A laboratory test certificate in accordance with ISO 10140-2:2010 shall be provided to demonstrate that the complete doorset achieves the sound reduction indices. Refer table 9.
- The doorset shall include acoustic compression seals to the head and jambs, and an acoustic automatic drop seal to the threshold. All seals shall be evenly compressed when the door is closed.
- For twin leaf doors the meeting stile shall be rebated and have an acoustic compression seal.

For standard doors (eg 30 dB R_W) the specification could include:

- The door leaf shall be of solid core timber construction at least 44 mm thick.
- Any glazed panels in the door shall be at least 6 mm thick and shall be fitted in the door leaf with effective seals.
- There shall be no penetrations through the door for locks or any other purpose.
- Effective acoustic compression seals shall be fitted to the head and jambs of the door frame. Door furniture shall be provided and the door leaf fitted so that the door leaf evenly compresses all seals when closed.
- The threshold of the door shall be close cut to the floor to minimise the gap under the door when closed.

Roofs and external walls

Again, the wall, ceiling or roof specification should be determined by an acoustics specialist to achieve the internal noise criterion. However, for walls, ceilings and roofs, the construction should be specified directly rather than acoustic performance. For a replacement wall lining a specification may include:

- The existing internal wall lining shall be completely removed and replaced.
- Building wrap shall be installed as required by the Building Control Authority. The wall cavity between the existing external wall and the new internal lining shall be filled with thermal insulation to meet the building code thermal R-value requirement of 1.9 or 2.0 (depending on location).
- The new wall lining shall comprise two layers of 13 mm thick plasterboard at least [X] kg/m^2 total.
- The joints in each layer of the wall lining shall occur over framing and be offset. Joints and fastener heads in the outer layer shall be taped and stopped. A bead of acoustic sealant shall be applied around the perimeter of the inner layer, and the outer layer shall be bedded onto that bead.

TABLE 9: DOORS SOUND REDUCTION INDICES

Octave band	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
Minimum sound reduction index (R)	[X] dB	[X] dB	[X] dB	[X] dB	[X] dB	[X] dB

CASE STUDY – SH1 PLIMMERTON – PAREMATA UPGRADE, PORIRUA (2002–2005)

The SH1 Plimmerton–Paremata Upgrade Project (2002-2005) in Porirua involved roadworks to widen the state highway through an existing urban residential environment. The designation conditions for the project, including acoustic mitigation requirements, were determined by the Environment Court, following several appeals of Transit New Zealand's initial decision (Environment Court case W52/2001). The acoustic treatment described in this case study was implemented as a separate contract to the main roading works, and was known as the Acoustic Mitigation Project.

The designation conditions include a requirement for the works to comply with the 'Transit Guidelines'[22] for road-traffic noise (effectively the predecessor to NZS 6806). The 'average noise design levels' from the Transit Guidelines are often quoted, but there is also a 'single event design criterion' intended to manage the effects of sleep disturbance from individual vehicle pass-bys. That single event criterion is achieved by the road being at least 12 m from houses. If this distance is not met then the Transit Guidelines required mitigation to achieve a 3 dB reduction in road-traffic noise levels (the rationale for the 3 dB reduction is not made clear in the Guidelines). For this project numerous houses were within 12 m of the state highway, and hence a 3 dB reduction was required.

Property fences were installed as noise barriers and in places this resulted in the required 3 dB reduction. However, in other areas barriers were not practicable or were not the property owner's preferred option, and instead individual houses were treated to achieve the 3 dB reduction. A total of 57 houses along Mana Esplanade and St Andrews Road were treated generally with new glazing and ventilation. Most work was conducted by a building contractor engaged by the Transport Agency (then Transit). For a small number of properties the owners choose to directly contract the works and the Transport Agency reimbursed receipted costs up to the amount that the Transport Agency's builder had quoted.

Management of the work

The works were proactively managed throughout the process by both the builder's foreman and the Transport Agency's consultant engineer. It was fortunate that the same project team responsible for overseeing the acoustic treatment was also involved in the main roading project upgrade works. This meant that an engineer was based on site and always available. This proved to be essential in monitoring progress and responding to issues and queries.

A key component to the management of the project was a detailed written agreement with individual

FIGURE 51: PHOTOGRAPH OF SH1 MANA ESPLANADE, TYPICAL OF THE SITE

property owners. It took significant time to make these agreements. The agreements covered most of the issues detailed in section 4.2, but did not include an encumbrance as recommended for future projects. In some cases houses changed ownership during the works, and the agreements needed to be revisited from the beginning with the new owners. During negotiations, the Transport Agency offered property owners independent advice from an acoustics consultant, not otherwise involved in the works.

The final cost of the supply and installation of the works was approximately $650,000. Fees for design, noise modelling and monitoring, specification and management of the contract would result in the overall costs being around $1 million. The upgrade project was controversial and most residents were opposed to it. Also, the construction site on this project was the residents' lounges and bedrooms. Despite this, the project team was successful in managing the work without attracting media coverage or similar.

Management lessons learned

- A capable builder was appointed who was able to effectively organise the works on a range of different types of buildings, despite the numerous challenges associated with this work. Selection criteria for contractors conducting works of this nature on future projects should be weighted towards workmanship, experience, timeliness and ability to engage with residents.
- The agreements did not impose timeframes. One property, where the owner choose to conduct the works themselves, is still outstanding (2012). This issue will be addressed for new projects if designation conditions follow those in section 4.2, which include detailed timeframes.
- It is critical to have detailed written agreement with property owners prior to the works.

Ventilation

A simple supply air fan was installed, generally in the roof space as shown in figures 33 and 34. Only rooms that qualified for glazing were supplied with ventilation. The system was required to have two air flow settings of 0.3 and 1.0 ACH (these are both less than recommendations now set out in this guide).

The user controls for the system are simple switches. The air supply to the fan can be remotely switched either to take air from the ceiling cavity in winter (becoming a heat transfer system as shown in figure 53), or to take outside air in summer. Where practicable, the intake for outside air was specified to be on the opposite side of houses to the state highway to take cleaner air. The system is required to be no more than 'PNC 30' (equivalent to approximately 35 dB L_{Aeq}).

The system was supplied to owners with two spare bag filters, a brief operation & maintenance guide, a 12 month defects maintenance period and 12 months additional warranty. The supply and installation of the ventilation system cost approximately $2000 per house (2002).

FIGURE 52: GLAZING UPGRADE WORKS IN PROGRESS

FIGURE 53: SCHEMATIC DRAWING OF SH1 PORIRUA VENTILATION SYSTEM

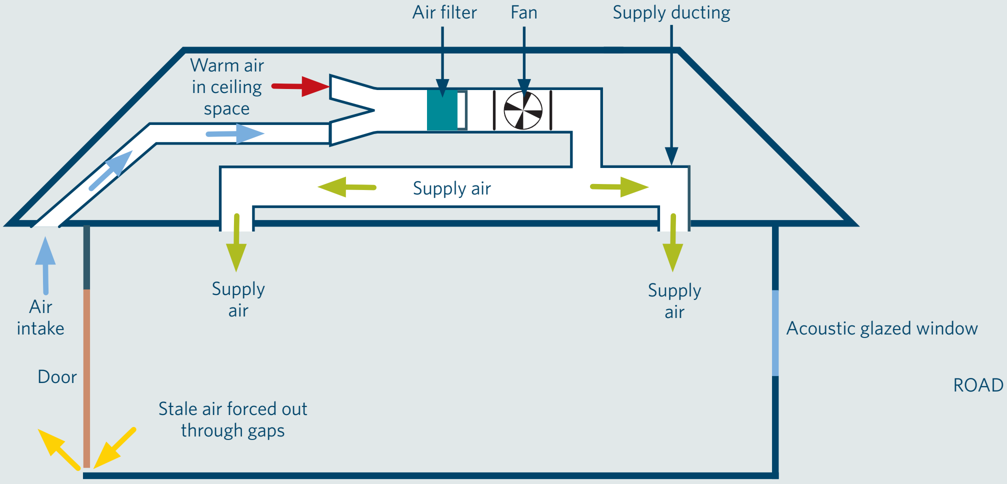


FIGURE 54: FAN AND INSULATED DUCTWORK IN ROOF CAVITY

Ventilation lessons learned

- As for the SH20 Mt Roskill case study, the use of a generic design was effective for most properties. There were difficulties where there was not a suitable ceiling cavity to install the fan into, or eaves for the air intake grille. Where houses had shallow or flat roofs without an appropriate ceiling cavity alternative enclosures for fans were created, for example in a wardrobe. This introduced additional issues with sound from the fan 'breaking out' through the wardrobe walls.
- No maximum air flow rate was specified so there could be significant variations in air flow between rooms.
- Residents generally wanted air conditioning (cooling and heating) as well as the ventilation that the system provided.

Glazing

A range of work was undertaken on windows including reglazing, replacing timber sashes, or replacing entire windows. The appropriate treatment for each window of each house was confirmed by an acoustics specialist. Where glazing was replaced either 7 mm thick or 9 mm thick acoustic laminated single glazing was used.

The average cost of the works to windows was $11,000 per house (2002), but this varied from houses just being reglazed (approximately $2,000) to houses that received new aluminium joinery (approximately $15,000).

Glazing lessons learned

- In some cases an effective seal could not easily be achieved when just replacing or refitting sashes rather than replacing an entire window. This was due to the varying condition and age of the timber windows.
- Where timber windows were reglazed some issues arose with the putty and painting of the putty. The entire frame should be repainted and not just the new putty. Scaffolding for second floor windows should be left in place for painting while the putty cures (typically 2-3 weeks). Ideally windows should be reglazed to align with dry times of the year. Consideration should be given to replacing windows including all framing, which can be more efficient to install and may achieve a better result for a relatively minor increase in cost.
- When determining the appropriate treatment to windows, it would have been a significant benefit to have had an experienced joiner present at the initial site visits. On a number of properties it was decided to refurbish windows or replace sashes, where a joiner would probably have been able to identify that it would be more appropriate to replace the entire windows. A joiner might also have identified one particular house where the Transport Agency ended up rebuilding a façade, as once a window was removed the wall framing and cladding was found to be rotten and a new window could not be refitted without refurbishing the entire wall (inside and outside).
- In one instance there was a complaint after the defects period that marks were appearing in the laminated glass. The glazing sub-contractor rectified the problem, but under the agreement it could have created an issue for the Transport Agency. This highlights the importance of robust specification and comprehensive commissioning.
- A variation was made to use stainless steel hardware on windows due to the marine environment. This should be included for future projects in similar areas.

FIGURE 55: EXAMPLE OF ROTTEN FRAMING FOUND WHEN WINDOW REMOVED

5

GLOSSARY

TERM	DEFINITION
Absorption	The loss of acoustic energy that occurs when a sound wave strikes a surface.
Acoustic clip	A device incorporating a flexible material to reduce transmission of sound through the structure of a plasterboard wall (or ceiling). Typically the clip is attached to the wall framing and then rails for the plasterboard are attached to the clip.
Air Changes Per Hour (ACH)	The number of times in an hour that the air within a room is replaced. For mechanical ventilation, typical habitable rooms require 1 ACH, while 3 ACH are usual for bathrooms and kitchens.
Annual Average Daily Traffic (AADT)	The vehicle count for an entire year in both directions past a point on the road, divided by the number of days in the year.
Altered Road	An existing road that is subject to alterations of the horizontal or vertical alignment and meets criteria defined in section 1.5 of NZS 6806, including certain sound level thresholds.
AS	Australian Standard.
Building-modification mitigation	Measures to reduce the effects of internal traffic noise levels in buildings, including acoustic insulation, voice amplification systems and building relocation. Refer to NZS 6806.
Buoyancy	Buoyancy is the effect that causes warm air to rise and cold air to sink. This effect is due to the difference in density of warm air compared with cold air.
Composite sound reduction index	The facade of a building is most commonly made up of a number of different constructions, each with their own sound reduction index. The overall sound insulation of a facade is known as the Composite Sound Reduction Index.
Conditions	Conditions placed on a resource consent (pursuant to section 108 of the RMA) or conditions of a designation (pursuant to subsection 171(2)(c) of the RMA).
Core	In the core of a building ventilation heat exchanger, heat is transferred from the warm, stale air leaving the building to the cool, fresh air entering the building or vice versa. The incoming and outgoing airflows are separated by a solid barrier and providing that there is a difference in temperature between the two airflows, heat from the warmer airflow will be transferred through the core to the cooler airflow.
Decibel (dB)	A unit of measurement on a logarithmic scale which can be used to describe the magnitude of sound pressure with respect to a reference value (20 μPa)

TERM	DEFINITION
Double-glazing	Two panes of glass separated by a cavity in the order of 12 mm to achieve thermal insulation. This does not provide effective sound insulation due to a resonance across the cavity.
Dry bulb temperature	The temperature measured by an ordinary thermometer. This is the temperature reported most commonly in weather reports.
Existing road	A formed legal road existing at the time when road-traffic noise from a new or altered road is assessed using NZS 6806.
Frequency	Refers to the number of cycles or revolutions per second – expressed in Hertz (Hz) – and determines the 'pitch' of a sound source, ie the higher the frequency, the higher the pitch.
Grille	A grille is the cover for the opening of a ventilation duct into a room or to outside.
Habitable space	A space used for activity normally associated with domestic living, but excluding any garage, bathroom, laundry, toilet (water closet), pantry, walk-in wardrobe, corridor, hallway, lobby, clothes-drying room or other space of a specialised nature occupied neither frequently nor for extended periods.
Head	The top part of a door frame.
Heat exchanger	In ventilation systems, this is a device that allows a warm fluid to exchange heat with a cold fluid. When both fluids are air this is specifically referred to as an air to air heat exchanger.
Heat recovery	The exchange of heat energy between a warm air supply and a colder air supply using a heat exchanger. The two air streams do not physically mix.
Heat transfer	The movement of heat energy from one location to another location using mechanical ventilation.
Hertz (Hz)	Unit of frequency, used for sound and vibration.
Jambs	The sides of a door frame, where the hinges are mounted, and in which the bolt/latch is located.
$L_{Aeq(24h)}$	Time-average sound level over a 24-hour period, measured in dB.
Mass	The weight of a material based on its size and density. For building materials this is often expressed per square metre: kg/m^2.
Meeting stile	The vertical joint between two leafs of a double door.
New road	Any road which is not an altered road and is to be constructed where no previously formed legal road existed.

TERM	DEFINITION
Noise	Noise may be considered as sound that serves little or no purpose for the exposed persons and is commonly described as 'unwanted sound'. If a person's attention is unwillingly attracted to the noise it can become distracting and annoying, and if this persists it will provoke a negative reaction. However, low or controlled levels of noise are not necessarily unreasonable.
NZS	New Zealand Standard.
NZTA	NZ Transport Agency: The crown agency responsible for, amongst other functions, the management and maintenance of the state highway network.
Octave and third octave bands	Octave or third octave bands consist of a range of frequencies, eg the 1 kHz octave band covers the range from 707 Hz to 1414 Hz and is made up of the third octave bands 800 Hz, 1 kHz and 1.25 kHz.
Protected Premises and Facilities (PPFs)	Spaces in buildings used for residential activities, marae, overnight medical care, or teaching (and sleeping in educational facilities and playgrounds within 20 m of the building). Refer to NZS 6806.
Refrigerant	In mechanical ventilation systems, a refrigerant is a substance that is used to change the temperature of the air. Heat is removed from the air by a reversible change in state of the refrigerant (eg from a liquid to a gas).
Resonances	Materials and constructions have particular frequencies at which they will resonate or vibrate more than at other frequencies. These resonances are controlled by stiffness and damping inherent within the construction/ material.
Reverse sensitivity	The vulnerability of an established activity such as a road to objection from new sensitive activities located nearby.
RCD	An electrical device that detects and disconnects a circuit when small changes in circuit current occur. This is different from a circuit breaker which disconnects the circuit when a large current spike is detected.
Secondary glazing	Two panes of glass separated by an air cavity 100 to 200 mm wide. This can provide effective sound insulation, but has poor thermal insulation due to convection in the cavity.
Sound	Changes in pressure levels that may be heard by humans. Unwanted sound can be considered as noise.

TERM	DEFINITION
Sound insulation	The ability of a material to prevent acoustic energy passing through its structure. This is different to 'thermal insulation'. Significant mass is generally required to provide good sound insulation, such as from plasterboard, brick or concrete. On the other hand, thermal insulation can be provided by lightweight materials such as polystyrene and fibreglass, which provide negligible sound insulation. Figure 7 provides a graph showing how sound insulation can vary with frequency.
Sound level difference (D)	The difference in sound level between the outside of a building and the inside of the building.
Soundfield system	A public address system typically used within a classroom to improve audibility of the teacher's voice for the pupils. The teacher often uses a wireless microphone.
Sound reduction index (R)	A measure of the sound insulation provided by a construction element in octaves or third octaves.
Spectrum	The frequency components that comprise a particular sound.
Structural mitigation	Measures to reduce noise such as low-noise road surface materials and noise barriers (including walls, fences and bunds). Refer to NZS 6806.
Threshold	The bottom of a door.
Trickle vent	A trickle vent is a small opening in a window frame or an external wall to allow a degree of ventilation in spaces when windows and doors are closed.
Wet bulb temperature	The temperature measured by a thermometer that has a piece of moist cloth wrapped around the bulb section. This type of thermometer is used in conjunction with a dry bulb thermometer and determines the moisture content of the air (humidity).
Weighted sound reduction index (R_w)	The combination of third octave band sound reduction indices for a particular construction, based on a standardised frequency characteristic of typical building materials. This is used to simplify sound insulation data so it can be presented as a single number for each construction.

6

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15-130 June 2015