Modelling buildings to predict barrier effects in traffic noise models

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Abstract

As a result of the New Zealand Government's 'Roads of National Significance' programme, there has been a significant number of roading projects requiring large and complex traffic noise models to inform assessments of the potential impacts of traffic noise. For roading projects in built-up urban areas, screening by the front row of houses affects traffic noise levels at properties further away from the road. This paper explores different approaches to modelling the screening effects provided by these buildings using SoundPLAN and compares the results with measured noise levels.

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1. Introduction

Since it was published in 2010, the New Zealand Standard NZS 6806:2010 "*Acoustics – Road traffic noise – New and altered roads*" (NZS 6806) has become the primary method of assessing noise from New Zealand public roads. When applied to large-scale projects, such as new motorways, bypasses and upgrades to major arterial routes, the study area can extend for kilometres, and include hundreds of potentially affected properties. Because of the multiple calculation points and sometimes complex geometries, calculations using simple methods, such as with a spreadsheet, are generally inefficient. As a result, 3-dimensional computer models are the preferred method of predicting traffic noise levels and developing noise mitigation options.

NZS 6806 requires predictions of traffic noise levels to be conducted in accordance with CRTN (Calculation of Road Traffic Noise) methodology [1]. This has been generally accepted as being the most appropriate method for predicting traffic noise in New Zealand, subject to adjustments for common road surfaces [2]. One element of the CRTN method is the barrier insertion loss, this being the reduction in noise at a receiver resulting from screening of the noise source by intervening terrain or structures. This is referred to in CRTN as the 'barrier correction'. The barrier correction is an important element of the overall calculation, as the reduction in noise level can be up to 20 decibels in extreme cases, significantly affecting the resulting traffic noise level.

Because predicted traffic noise levels are used to inform decisions regarding noise mitigation, incorrect modelling of barriers could result in inappropriate specification of noise mitigation measures. For instance, the under-prediction of the barrier loss (resulting in higher traffic noise levels at receivers) may lead to the specification of a low-noise road surface, and subsequent increased costs. On the other hand, over prediction of barrier loss could result in insufficient noise mitigation being included in the design of the project, leading to significant unanticipated adverse noise effects, unexpected costs and loss of goodwill.

For large scale projects, a standard approach to modelling buildings to accurately predict barrier loss is required to enable the acoustic consultant to provide accurate, timely and reliable advice.

Most residential buildings in New Zealand have relatively complex geometries, including pitched roofs. This paper explores methods for modelling of these more complex building shapes and covers the following:

- General overview of the CRTN traffic noise prediction method, with particular reference to how intervening structures are taken into account.
- An outline of four general approaches to modelling buildings in SoundPLAN, including an overview of the advantages and disadvantages from a modelling perspective, and a comparison of predicted noise levels for each method.
- Development of the flat-topped building approach to determine a standard building height.
- A comparison between traffic noise levels predicted using the flat-topped building approach and measured traffic noise levels at a location in Christchurch.

2. The CRTN calculation method

In essence, the traffic noise calculation method defined in the CRTN standard comprises three core parts:

- Calculating the basic noise level based on parameters affecting noise emissions including traffic flow, percentage heavy vehicles, traffic speed, gradient and road surface.

- Determining appropriate corrections to the basic noise level to account for the propagation path including distance, intervening structures and ground cover.
- Adjusting for the specific receiving environment to take into account reflection effects and angle of view.

The calculation of the barrier correction term is included in the second part of the method described above, and is the only element of the CRTN method considered in this paper.

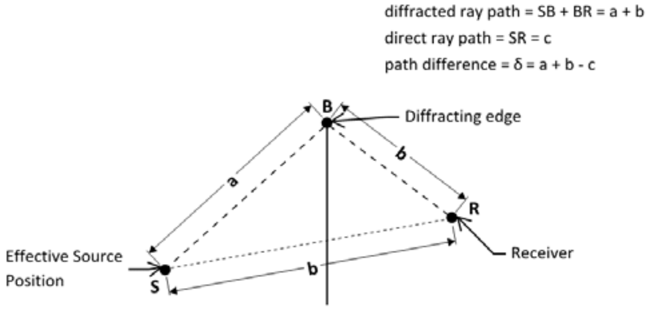

Figure 1: Geometry to evaluate the path difference for obstructed propagation

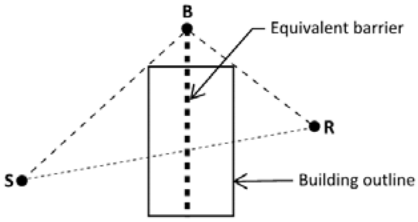

Figure 2: Equivalent barrier location used to calculate the barrier correction with a flat-topped building

Once the path difference is determined from the propagation geometry, the barrier correction, in decibels, is calculated using a polynomial expression 2.

3. 3-Dimensional modelling approaches

The tools most applicable to modelling buildings in SoundPLAN are the Building, Noise Barrier, and Floating Screen tools. These key aspects of how these tool work are:

- The Building tool creates a horizontal, flat-topped building with a user-entered footprint and vertical walls.
- The Noise Barrier tool creates vertical walls of a user-defined height.
- The Floating Screen is essentially a Noise Barrier that does not have to be vertical. It therefore can be used to create angled planes.

It is important to remember that SoundPLAN merely applies the selected calculation standard, in this case CRTN. Therefore, while complex geometries can be modelled in SoundPLAN, the accuracy of the predicted noise levels is still limited to how these geometries are interpreted by the calculation standard.

Four main modelling approaches using these tools were considered:

- Detailed modelling of the building including pitched roofs.
- Vertical wall parallel with the road axis representing the equivalent barrier/roof ridge height.
- Flat-topped building based on the actual footprint.
- A combination of flat-topped building with a noise barrier at the roof ridge.

These methods are described in the following sections, with brief comments regarding key issues from a modelling perspective. Note that some of the following comments with respect to modelling may only apply to SoundPLAN models, and may not be applicable to other computer noise modelling software packages.

3.2 Pitched roof building model

Buildings with pitched roofs can theoretically be input in SoundPLAN by a skilled user implementing a combination of tools.

From a modelling point of view, this method has some drawbacks when modelling on a large scale. Namely:

- The method is very time consuming, as the roof of each building must be constructed separately and in addition to the main building structure as described above. In some cases each individual roof plane would need to be entered separately.
- The method cannot be easily error-checked or modified on a large-scale, and has many possibilities for error.

The main advantage of this approach, from a modelling perspective, is that the Building tool, as well as defining the geometry of a structure, also provides options for the specification of receiver positions. That is, entering a building defines the receiver position at the same time. This streamlines the modelling process, ensures that calculation positions are in the correct position, and enables modifications to receiver positions at all positions to be made quickly.

3.3 Individual noise barrier

To model buildings with pitch roofs using this method, a noise barrier is placed with the top edge at the ridgeline of the roof.

From a modelling perspective, the key issues with adopting this approach stem from the requirement to enter additional receivers for every assessment position.

Namely:

- Entering receiver positions for every position of interest takes a significant amount of time for large

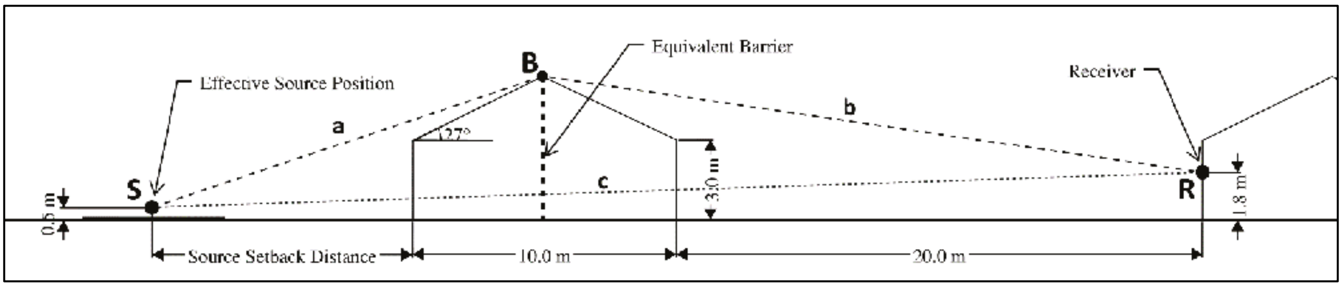

Figure 3: 2-dimensional geometry including ray paths and equivalent barrier position

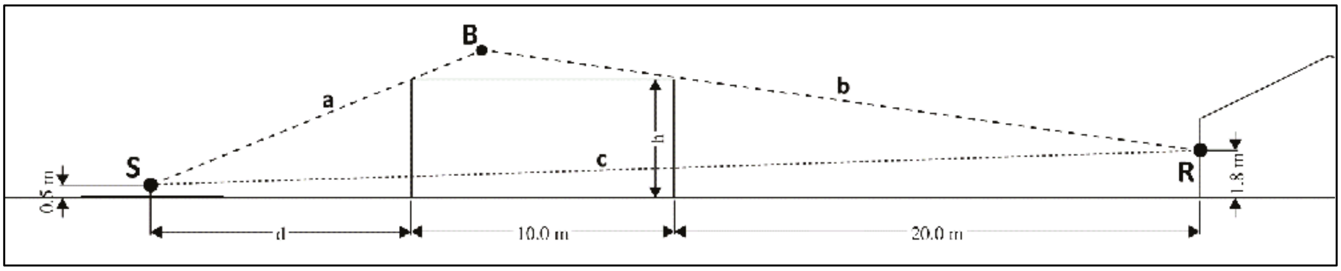

Figure 4: 2-dimensional geometry with flat-topped building ray paths

models.

- If reflections off noise barriers are included, the calculated noise level at the associated receiver(s) will not be a free-field level and cannot be simply adjusted.
- If reflections off noise barriers are excluded to enable free-field noise levels to be calculated, the effect of reflections on other receiver positions will not be taken into account, resulting in lower noise levels.

3.4 Flat-topped buildings

The footprint of a building can be defined in SoundPLAN by tracing the perimeter of the structure from a high definition aerial photograph, or by geo-located digital building footprints imported directly into the model. Building heights are usually set using one of the following three approaches:

- Building height set at eave height which does not take into account the pitched roof.
- Building height set at ridgeline height, essentially increased the height of the walls.
- Building height set at value between the eave and ridge height to approximate the effect of the pitched roof on screening of the source.

From a modelling perspective, this approach has the following advantages:

- Multiple buildings can be entered quickly when geo-located digital building footprints are available, avoiding the need to manually define each individual building based on aerial images.
- Height information is sometimes included in the building footprint data, assisting in the identification of multi-storey buildings and positioning receivers. This is especially useful where buildings overlook the road being assessed.
- Receiver positions for noise level calculations can be associated with buildings and do not need to be entered separately.

However, the most significant flaw in this approach is that the vast majority of residential buildings in New Zealand have pitched roofs. Therefore, the potential accuracy of this approach relies on closely matching the barrier correction calculated by the pitched roof approach.

3.5 Flat-topped building and noise barrier combination

This combination of modelling approaches capitalises on the significant advantages of the flat-topped building method, while also negating the main issues with both standalone approaches. The only real disadvantage to this method is the extra time required to input the noise barriers, which for large-scale projects may be significant.

4. Comparison of predicted noise levels

A simple scenario was modelled in SoundPLAN using a combination of the different modelling approaches.

Figure 3 shows the geometry of the scenario that was modelled. Figure 4 shows how this might be modelled by a flat-topped building. The lines marked a, b and c are the ray paths used to calculate the path difference, as shown earlier in Figure 1 and Figure 2.

The receiving position is 20 m behind the buildings closest to the road source. A 20 m distance is considered representative of the common scenario where houses are on opposite sides of a residential road, separated by small front yards, a footpath and grass verge on either side of the street, and the street itself. NZS 6806 defines the ground floor assessment position as between 1.2 m and 1.5 m above the floor level [3]. The receiver was located 1.8 m above the ground and therefore is valid for buildings with foundation heights between 0.3 m and 0.6 m.

A source setback distance of 50 m was used, with propagation over 100% hard (i.e sound reflecting), flat ground between source and receiver. Arbitrary traffic parameters were used, as these only affect the overall level, not the difference between each method. The predicted noise levels are shown in Table 1.

Table 1: Comparison of predicted noise levels

Predicted traffic noise level (dBA)				
Pitched Roof	Noise Barrier*	3 m High Flat-top	5.5 m High Flat-top	Combination Model**
50.5	50.3	53.4	49.2	50.4

* 5.5 m high barrier located at ridge position

** 3 m high flat-topped building and 5.5 m high noise barrier at ridge position.

In summary, the results for the simple model show the following:

- Predicted noise levels are similar for all modelling approaches which model the roof ridge (i.e. pitched roof, noise barrier and combination). As there are significant benefits, from a modelling perspective, associated with the use of the combination approach, the pitch room and noise barrier approaches were not developed further.
- Predicted noise levels for flat-top buildings vary by almost 4 dB depending on the height selected.

As a result of the above, the flat-topped building approach was progressed further in order to determine what height of building results in predicted noise levels in line with the more detailed approaches. This is discussed in the following section.

4. Developed flat-topped building model

As discussed, there are significant benefits to the modeller in adopting the flat-topped building model approach. On the basis that CRTN barrier correction calculation method correctly predicts the insertion loss of a structure when the correct geometry is modelled, the key challenge is therefore determining the building height that most accurately predicts the barrier correction calculated with the other, more geometrically correct, approaches. This section outlines the process by which this was determined.

4.1 Methodology

The simple scenario used to compare the modelling approaches was used to analyse a range of flat-topped building heights (refer to Figure 2), as follows:

- The barrier correction was calculated for setback distances between the source and front-row varying from 80 m to 5 m. The results therefore take into account the range of geometry that might be found in real life. For example, an upgrade to an existing urban road would most likely bring the road significantly closer to the front-row buildings than a new motorway located on the fringe of an urban area.
- As seen in Table 1, the barrier correction calculated for a pitched roof building is very similar to that calculated for a simple noise barrier. To determine which flat-topped building height was most accurate for the range of source distances, the predicted CRTN barrier correction for each building height was compared with the CRTN barrier correction for the equivalent barrier. This is a 5.5 m high barrier located at the building ridge position (refer to equivalent barrier in Figure 1).
- To restrict the models to realistic geometries, buildings between 3 m and 5.5 m in height were assessed. 3 m is the eave height of the theoretical building and therefore a reasonable minimum height. 5.5 m is the ridge height and therefore a reasonable maximum height limit.

4.2 Results

The calculated barrier corrections for the following three scenarios are presented:

- Scenario 1: 3 m high building, representative of models based on the building eave height.
- Scenario 2: 5.5 m high building, representative of models based on the building ridge height (5.5 m is the ridge height for the reference scenario).
- Scenario 3: 4.4 m high building, selected as the giving the best approximation of the reference scenario for the range of source positions modelled.

The results are presented in Table 2 and Figure 5, with a detailed data table contained in Appendix A.

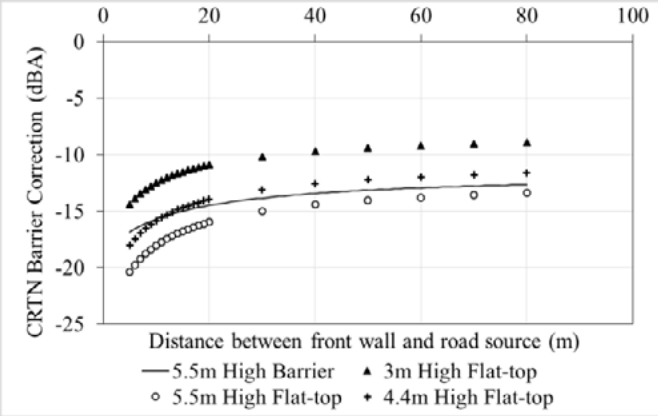

Figure 5: CRTN barrier correction for flat-topped buildings in reference scenario

Table 2: CRTN barrier correction for flat-topped buildings in reference scenario

Source Setback (m)	CRTN Barrier Correction (dBA)			
	Reference Scenario	3 m High Flat-top	5.5 m High Flat-top	4.4 m High Flat-top
80	-12.7	-8.9	-13.4	-11.6
70	-12.8	-9.0	-13.6	-11.8
60	-12.9	-9.2	-13.8	-12.0
50	-13.1	-9.4	-14.0	-12.2
40	-13.4	-9.7	-14.4	-12.6
30	-13.8	-10.2	-15.0	-13.1
20	-14.5	-10.9	-16.0	-14.0
15	-15.0	-11.5	-16.8	-14.7
10	-15.7	-12.5	-18.0	-15.8
5	-16.8	-14.4	-20.4	-18.0

In summary, the results show the following:

- Calculated barrier corrections for flat-topped buildings modelled at eave height are typically around 3 dBA to 4 dBA smaller (i.e. less reduction in noise level) than the barrier correction for the reference scenario.
- The barrier correction with a 3 m high flat-topped building differs from the reference scenario barrier correction relatively consistently across the modelled range of source setback distances.
- Calculated barrier corrections for flat-topped buildings based on the ridge height are within 1 dBA of the reference scenario for source setbacks greater than 40m, and differ by more than 2 dBA for source setback distances less than 13 m. The difference is most significant with small setbacks, and the barrier correction is always larger (i.e. more negative), as would be expected.
- The calculated barrier correction for a 4.4 m high flat-topped building is within 0.5 dBA of the reference scenario for source setbacks between 20 m and 8 m, and within 1 dBA for source setbacks between 6 m and 80 m.

5. Traffic noise survey

To test the accuracy of the flat-topped building model, noise levels calculated by a SoundPLAN computer noise model for a section of QEII Drive (SH74) were compared with measured noise levels.

Traffic noise level measurements were conducted near QEII Drive (SH74) in Christchurch on the afternoon of 8 July 2014. Figure 6 shows the location of measurement positions A, B and C.

Figure 6: Measurement and calculation positions (Imagery: Google, 2012)

A logging sound level meter was erected at Position A, recording one-second A-weighted average noise levels (L_{Aeq}) for the duration of the survey. Multiple short-duration L_{Aeq} measurements were recorded at Position B and C. The logger data was post-processed to determine the LAeq noise level at Position A that correlated to each measured noise level at Position B and C. The noise level difference between Position A and Position B or C was then calculated.

6. SoundPLAN traffic noise model

A 3-dimensional noise model was constructed in SoundPLAN [4]. The position of the buildings, road and solid fences were based on aerial images. The underlying terrain model was flat and 100% hard.

Free-field receivers were located at Positions A, B and C, shown in Figure 6. Additional receivers were also attached to the front façades of two buildings, at Positions D and E, to determine the calculated level difference at Position C compared to front-row buildings.

Traffic noise levels were calculated in accordance with the CRTN method, with arbitrary values set for traffic flow, average speed, surface correction and percentage heavy vehicles.

7. Results - Comparison with measured noise levels

Table 3 contains both the measured and calculated difference in traffic noise level at Position B and C, compared to Position A. Note that the level differences in Table 3 include factors such as distance from the road and reflections off nearby structures, and are not directly comparable to the CRTN barrier correction.

The results in Table 3 show that, for all building heights, the calculated level difference at Position B and C is smaller (i.e. less r) than the measured results.

Table 3: Difference in traffic noise level compared to Position A

Position	Measured level difference (dBA)	Calculated level difference (dBA)		
		3 m high buildings	5.5 m high buildings	4.4 m high buildings
B	-22.8	-15.4	-20.2	-18.4
C	-22.0	-15.6	-19.2	-17.9

8. Discussion

8.1 Approach to modelling buildings

The practical advantages associated with modelling single-storey dwellings as flat-topped boxes far outweigh the potential inaccuracies associated with the fundamental deviation from modelling the true shape of most buildings. It is therefore anticipated that future developments in 3-dimensional modelling of buildings for traffic noise modelling will be based around this approach.

A 4.4m high flat-topped building result in a CRTN barrier correction that most closely correlates to the reference scenario for source setbacks between 5 m and 80 m. 4.4 m may therefore be a reasonable default building height for traffic noise models.

It is interesting to note that SoundPLAN's recommended approach to modelling buildings is to use flat-topped buildings at the mean building height. If the ridge height is not known, SoundPLAN calculates this by adding half the floor height onto the overall building height. For a single storey building with a 3 m first floor height, this would give a building height of 4.5 m.

On some projects, aspects of the reference scenario geometry, such as eave height or roof pitch, may be clearly inapplicable. For example, areas of the country with the potential for high snowfall are likely to have steeper roofs, or a particular area may have consistently higher foundations due to potential flood risk. In this case, it would be possible for the modeller to fine-tune the building height by reproducing the calculations undertaken in this paper to derive the 4.4 m height. However, the impact of these geometric changes is unlikely to alter the building height by more than a few hundred millimetres, with a corresponding change in barrier correction of a few fractions of a decibel at most. Therefore, it is unlikely that this would be warranted for most projects, and the 4.4 m height will still provide a good level of correlation.

One aspect of traffic noise modelling not covered by the reference scenario is the potential impact on noise levels at multi-storey second-row dwellings behind single-storey front-row dwellings, or where buildings have the potential to overlook the main carriageway due to elevated terrain. The degree of shielding provided by the front-row buildings is likely to be a key factor affecting noise levels at the second row buildings and will be affected by how both the receiver position and front-row buildings are modelled.

8.2 Predicting noise levels for assessment

Even with flat-topped buildings with walls the same height as the ridge of the peaked roof, modelled noise levels are around 3 dBA higher than measured noise levels. This suggests that calculations performed using the CRTN method will over-predict traffic noise levels at receivers with significant intervening structures.

While it is generally preferable to err on the conservative side when predicting noise levels for any assessment of noise effects, the impact of incorrect predictions on an assessment under NZS 6806 are potentially significant, as discussed at the start of this paper.

9. Future work

Traffic noise modelling and comparison with measured levels at more sites need to be undertaken to confirm the apparent over-prediction of traffic noise levels and suggested 4.4 m building height.

The reference model used in this paper could be modified to consider situations such as multi-storey second-row buildings, significant terrain variations, and where screening is dominated by a noise barrier in front of front-row dwellings.

An in-depth investigation of the potential impact on NZS 6806 traffic noise assessments, taking into account other real-life scenarios and the complete assessment process applied to large-scale projects, would provide valuable information to acoustic consultants and other parties involved in roading projects. A review of recent major projects is one potential starting point.

10. Conclusions

Buildings in 3-dimensional traffic noise models are recommended to be modelled using flat-topped buildings. Adopting this approach will enable modellers to benefit from the expected quality and availability of digital data, which is only expected to increase, by increasing their modelling accuracy and efficiency.

Analysis of a reference scenario based on generic building geometry shows that flat-topped buildings with a height of 4.4 m for single-storey buildings give the best correlation with the CRTN barrier correction

Acknowledgments

I would like to thank my colleagues in the Marshall Day Acoustics Christchurch office, particularly Jon, Stuart, Rob and Aaron, for the many challenging and enlightening discussions about the vagaries of computer noise modelling.

Appendix A - Detailed CRTN barrier correction

Table A1: CRTN barrier correction

	Reference Scenario	3m High Flat-top		5.5m High Flat-top		4.4m High Flat-top	
Source Setback (m)	Calculated CRTN Barrier Correction (dBA)	Calculated CRTN Barrier Correction (dBA)	Deviation from Reference Scenario (dBA)	Calculated CRTN Barrier Correction (dBA)	Deviation from Reference Scenario (dBA)	Calculated CRTN Barrier Correction (dBA)	Deviation from Reference Scenario (dBA)
80	-12.7	-8.9	**3.8**	-13.4	**-0.8**	-11.6	**1.0**
70	-12.8	-9.0	**3.8**	-13.6	**-0.8**	-11.8	**1.0**
60	-12.9	-9.2	**3.8**	-13.8	**-0.8**	-12.0	**1.0**
50	-13.1	-9.4	**3.7**	-14.0	**-0.9**	-12.2	**0.9**
40	-13.4	-9.7	**3.7**	-14.4	**-1.0**	-12.6	**0.9**
30	-13.8	-10.2	**3.7**	-15.0	**-1.2**	-13.1	**0.7**
20	-14.5	-10.9	**3.6**	-16.0	**-1.5**	-14.0	**0.5**
19	-14.6	-11.0	**3.6**	-16.1	**-1.5**	-14.1	**0.5**
18	-14.7	-11.1	**3.5**	-16.2	**-1.6**	-14.2	**0.4**
17	-14.8	-11.2	**3.5**	-16.4	**-1.6**	-14.4	**0.4**
16	-14.9	-11.4	**3.5**	-16.6	**-1.7**	-14.5	**0.3**
15	-15.0	-11.5	**3.5**	-16.8	**-1.8**	-14.7	**0.3**
14	-15.1	-11.7	**3.4**	-17.0	**-1.9**	-14.9	**0.2**
13	-15.2	-11.8	**3.4**	-17.2	**-2.0**	-15.1	**0.2**
12	-15.4	-12.0	**3.3**	-17.4	**-2.1**	-15.3	**0.1**
11	-15.5	-12.2	**3.3**	-17.7	**-2.2**	-15.6	**0.0**
10	-15.7	-12.5	**3.2**	-18.0	**-2.3**	-15.8	**-0.1**
9	-15.9	-12.8	**3.1**	-18.4	**-2.5**	-16.2	**-0.3**
8	-16.1	-13.1	**3.0**	-18.8	**-2.7**	-16.5	**-0.4**
7	-16.3	-13.4	**2.9**	-19.2	**-2.9**	-16.9	**-0.6**
6	-16.6	-13.9	**2.7**	-19.8	**-3.2**	-17.4	**-0.9**
5	-16.8	-14.4	**2.4**	-20.4	**-3.5**	-18.0	**-1.2**

References

1. Calculation of Road Traffic Noise, United Kingdom Department of Transport and Welsh Office
2. New Zealand Standard NZS 6806:2010 "Acoustics - Road-traffic noise - New and altered roads", Section 5.3.2 (c)
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4. SoundPlan 7.3, Braunstein + Berndt GmbH