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Lightweight noise barriers: The real-world effects of panel surface mass and absorption on acoustic performance

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ABSTRACT

Current practice in noise barrier design places strong emphasis on the selection of barrier materials with relatively high panel surface mass. Common rules-of-thumb suggest minimum surface masses of between 8 and 15kg/m^2. For rooftop mechanical plant equipment screens, there may be a desire to utilise materials which are lighter and easier to install; such as solid aluminium, or aluminium composite material (ACM) sheet. Such materials may have a surface mass as low as 4kg/m^2.

Based on the results of full-scale physical testing, this study investigated the insertion loss effects of varying the panel mass, internal sound absorption, and barrier configuration for typical screened-off plant enclosures with open tops. Comparisons were made between the physical test results and SoundPLAN computer modelling, which showed the computer modelling significantly overestimated the barrier losses.

It was found, for the measured plant enclosure configurations, there was an almost insignificant performance increase in doubling the surface mass of the enclosure material from 5.4kg/m^2 to 10.8kg/m^2. The introduction of sound absorption into the enclosure showed good barrier loss improvements. The introduction of a secondary front screen also proved beneficial at reducing noise spill under the plant screen.

Finally, a simple algorithm is presented in this paper for estimating the reduction in noise barrier performance for lightweight barriers, based on a correction for the transmission loss through the barrier material.

1 INTRODUCTION

With noise barrier design, there are various considerations to ensure that the barrier system provides sufficient noise attenuation for the receivers. However, general practice places strong focus on the selection of barrier materials with high panel surface mass, whilst potentially overlooking other aspects such as the effects of barrier sound absorption and secondary barriers.

Common rules-of-thumb suggest minimum barrier material surface masses of between 8 and 15kg/m^2. However, for open-top mechanical plant equipment screens, for example, there may be a desire to utilise materials which are lighter, more cost effective, and easier to install. Materials such as solid aluminium, or aluminium composite material (ACM) sheet may simplify barrier design, installation times and cost. Such materials may have a surface mass as low as 4kg/m^2.

The following acoustic barrier design considerations were investigated during this study:

1.1 Panel surface mass

It is common practice in barrier loss calculations to assume that the performance of a barrier system is controlled entirely by the sound diffracting over the top of the barrier rather than through the panel itself. It is therefore assumed that these panels have an infinite mass and transmission loss, and consequently, the specifications for barrier surface mass are often selected conservatively on the high side.

Determining the *minimum* surface mass of the barrier panels, however, is necessary in optimising materials and production costs.

1.2 Absorption

To minimise the amount of sound being reflected and then spilling outside an open top enclosure, the addition of an acoustically absorptive material inside the enclosure is typically beneficial. Therefore, it is of interest to determine the effectiveness and degree of sound reduction achieved when acoustic absorption is added to the inside surface of a barrier system.

1.3 Secondary barriers

Due to the nature of raised platforms on pitched roofs, an airgap between a barrier wall and the roof cladding is often required for ease of installation and also for the supply airflow to plant equipment. This presents an acoustic weakness where sound can spill out from under the barrier into the environment. This instigated the idea that a secondary barrier could be installed around the perimeter of the main enclosure, overlapping the airgap, in attempt to minimize the propagation of plant equipment noise from underneath the main barrier (see Figure 1, right-hand-side).

2 PRELIMINARY COMPUTER MODELLING

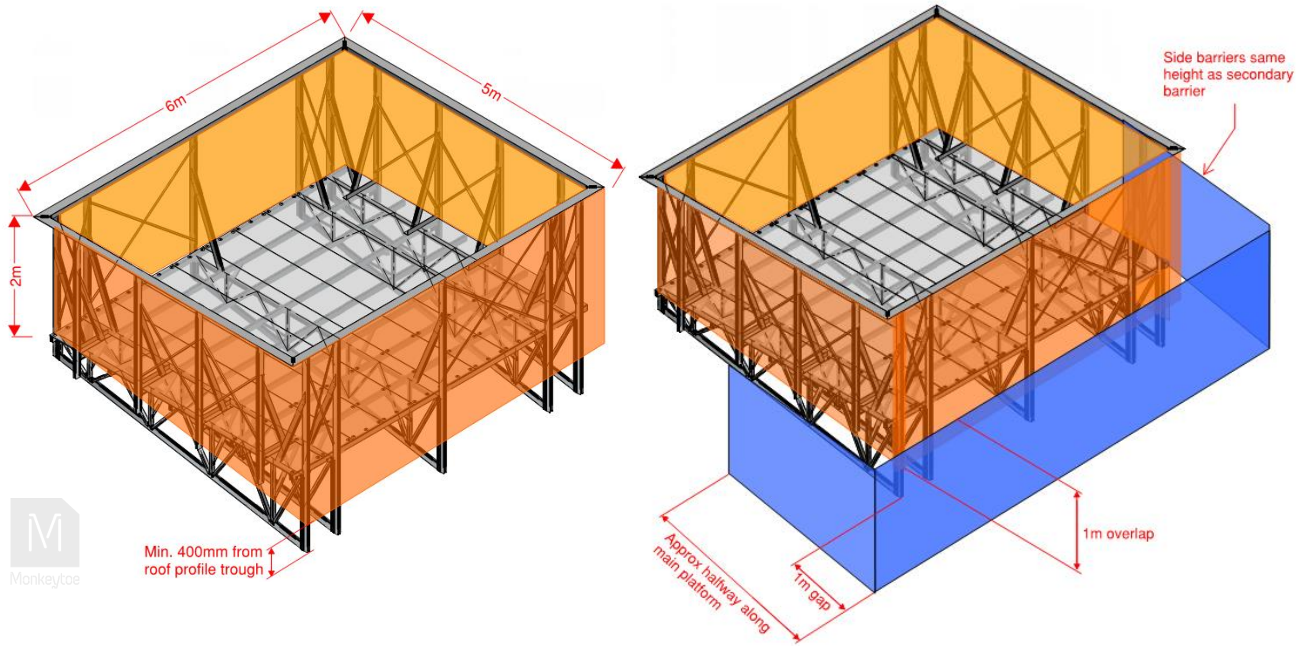
Preliminary computer simulations of a typical proprietary rooftop plant enclosure were created using SoundPLAN 8.0 and modelled with the ISO 9613-2:1996 industrial noise standard. These initial simulations were used to determine the likely performance of each of the physical testing scenarios described below.

3 PHYSICAL TESTING

Once various barrier configurations were modelled and estimations of performance were obtained, full-scale testing was then conducted. The following sections detail the configurations tested and the testing methodology used.

3.1 Plant enclosure configurations

Figure 1 below depicts the selected configurations that were tested to validate the effects of the various barrier design considerations. Each barrier panel was initially constructed from 2mm thick aluminium sheet.



#	Configuration	Description
1	Enclosed plant platform	The baseline configuration of the plant platform enclosed by noise barriers (orange) with an open top and a ventilation opening around the lower perimeter.
2	Enclosed plant platform + absorption	Same as configuration 1, but with absorptive panels installed on all inside vertical surfaces of the enclosure.
3	Enclosed plant platform + secondary barrier	Same as configuration 1, but with a secondary barrier (blue) installed in front to reduce noise spill under the main enclosure.
4	Enclosed plant platform + absorption + secondary barrier	Same as configuration 3, but with absorptive panels installed on all inside vertical surfaces of the enclosure, as well as on the front barrier.
5	Enclosed plant platform + absorption + secondary barrier AND doubled main barrier surface mass	Same as configuration 5, but with the surface weight of the main enclosure barrier doubled by adding a second layer of 2mm aluminium.

Source (Chen, K, Beresford, T, 2019)
Figure 1: Tested barrier configurations

3.2 Material data

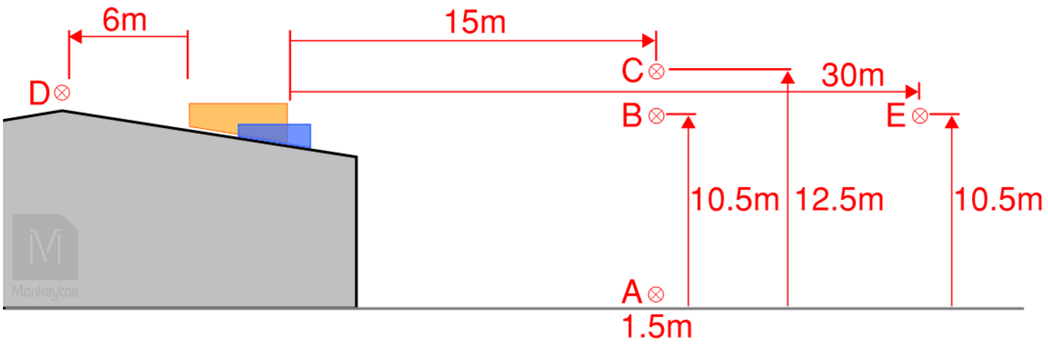
The following table details the material properties of key elements of the tested barrier system.

Table 1: Barrier material data

Frequency, Hz																
100	125	160	200	250	315	400	500	630	800	1k	1.25k	1.6k	2k	2.5k	3.15k	4k	5k
Main barrier: 2mm Aluminium, Transmission Loss (dB)																	
11.6	15.0	14.2	14.6	16.2	17.2	19.6	21.0	22.7	24.4	26.3	28.3	30.1	31.4	32.5	33.2	33.0	31.5
Absorptive panel: 50mm thick, Sound Absorption Coefficient α																	
0.13	0.16	0.28	0.40	0.69	1.13	1.01	0.99	1.03	1.12	1.09	1.07	1.02	1.09	1.05	0.97	0.91	0.89

3.3 Testing locations

The following diagram depicts the distances and locations where the sound pressure level measurements were taken, relative to the enclosure and ground level.

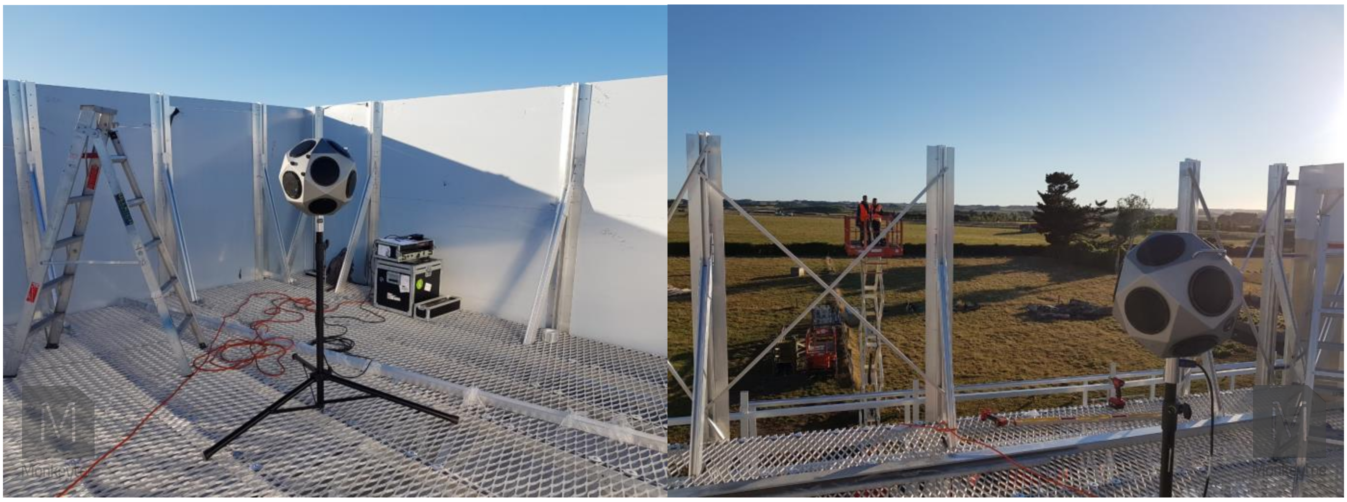


Source (Chen, K, Beresford, T, 2019)
Figure 2: Sound pressure level measurement locations

The microphone position 10.5m above ground was level with the sound source inside the enclosure.

3.4 Methodology

The loudspeaker was placed in the centre of the platform, 2.5m from the front barrier and 3m from the sides and at a height of approximately 1.5m from the mesh floor. This position was maintained throughout the testing process. The height of the barrier from the mesh floor was 2.0m, giving a 0.5m difference between the height of the source and the top of the barrier.

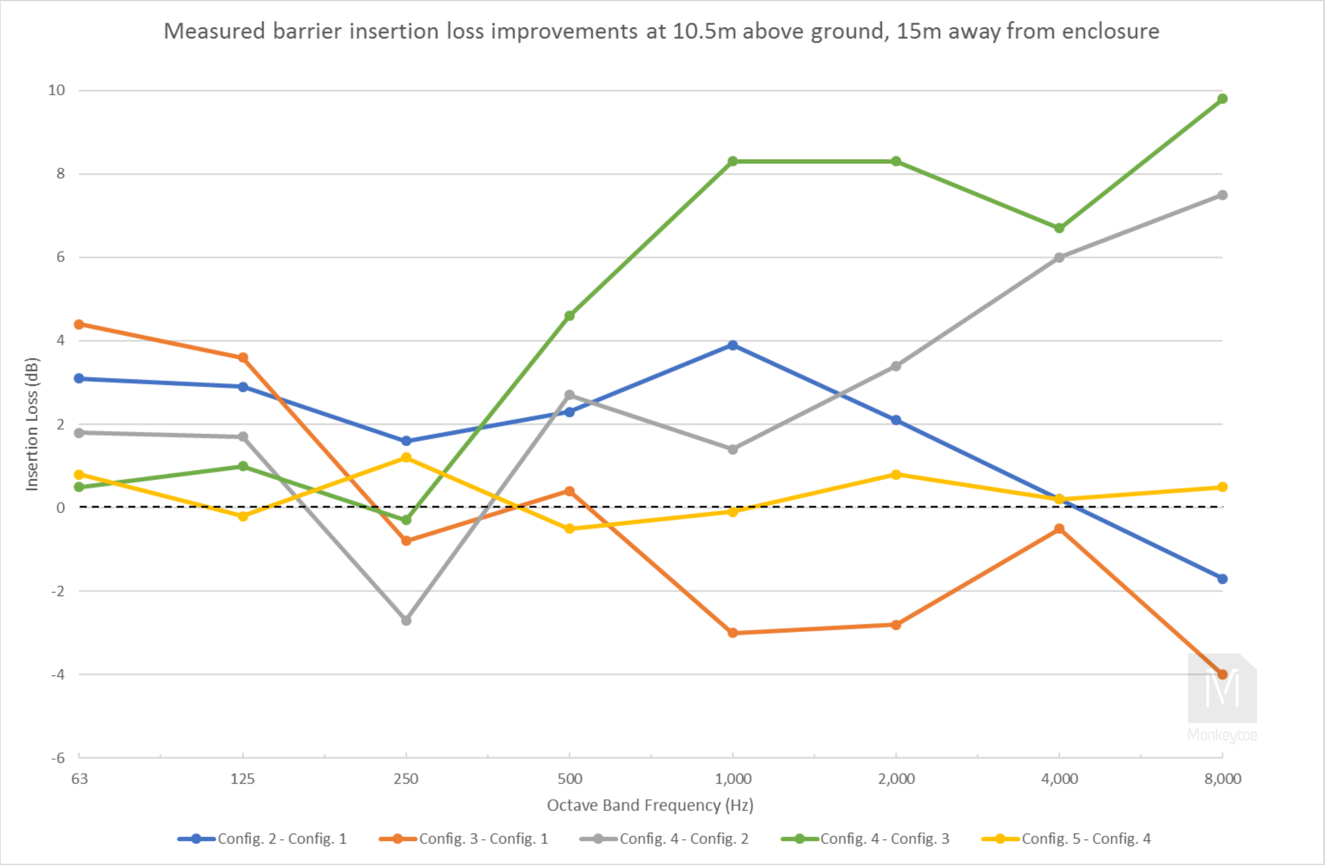


Source (Chen, K, Beresford, T, 2019)
Figure 3: Loudspeaker placement within enclosure and measurement positioning

4 RESULTS

4.1 Physical testing

The following graph depicts the insertion losses measured for each enclosure configuration. These graphed data were taken from the measurement position 10.5m above ground (approximately level with the sound source) and 15m away from the enclosure, and are representative of the general trends of the various barrier configurations.



#	Configuration	#	Configuration
1	Enclosed plant platform	4	Enclosed plant platform + absorption + secondary barrier
2	Enclosed plant platform + absorption	5	Enclosed plant platform + absorption + secondary barrier AND doubled main barrier surface mass
3	Enclosed plant platform + secondary barrier		

Source (Chen, K, Beresford, T, 2019)
Figure 4: Insertion loss comparisons

4.2 Computer modelling

The following table details the variance in results when comparing the real-world measured values with the initial computer model.

Table 2: Sample of measured results versus initial computer model

Frequency (Hz)	63	125	250	500	1000	2000	4000	8000	dBA
Configuration 1: SPL Comparison @ 10.5m height, 15m distance (dB)									
Measured	67.4	73.0	67.2	63.9	57.4	57.2	55.9	43.7	66
Uncalibrated Model	58.8	66.7	63.7	60.7	56.5	54.1	51.9	43.7	63
Difference	-8.6	-6.3	-3.5	-3.2	-0.9	-3.1	-4.0	0.0	3
Configuration 2: SPL Comparison @ 10.5m height, 15m distance (dB)									
Measured	64.3	70.1	65.6	61.6	53.5	55.1	55.7	45.4	64
Uncalibrated Model	58.8	66.7	63.7	59.1	53.0	48.7	45.4	36.8	61
Difference	-5.5	-3.4	-1.9	-2.5	-0.5	-6.4	-10.3	-8.6	3

5 DISCUSSION

5.1 Differences between computer modelling and physical measurement results

Significant differences between the SoundPLAN 8.0 (ISO) model and physically measured results were encountered during the study. The sample results in Table 2 show that the computer model substantially overpredicted the performance of the barrier system, with the largest deviations in the 63-125 Hz and 2k-8k Hz frequency bands. It is the authors' views that this was due to SoundPLAN not accurately modelling the reverberant build-up within the enclosure, even with a high reflection order selected in the calculation setup.

These results are included here as a warning to designers who are using SoundPLAN modelling for fully boxed-in enclosures, where the reverberant build-up within the enclosure is relatively high. For simple single barriers, where reverberant build-up is not expected to occur, this overprediction in performance may not be as apparent.

5.2 Improvements with the introduction of sound absorption

Looking at the plots in Figure 4, comparing Config. 2-1 and Config. 4-3, the addition of enclosure absorption provided a good improvement in sound reduction across most of the frequency spectrum. Looking at Config 4-3, specifically, shows a substantial increase in performance from 500Hz to 8kHz, where a lot of the high frequency sound was absorbed rather than leaking over or under the main barrier. This indicated that the addition of absorption to the inside surface of a barrier system was effective at increasing barrier performance, as it significantly reduced the reverberant sound within the enclosure from spilling out.

5.3 Improvements with the secondary front barrier

The addition of a secondary barrier proved to be somewhat effective at minimizing sound leakage from under the main barrier. Looking at Config. 4-2, it shows a considerable amount of high frequency sound being blocked and absorbed before reaching the microphone. However, looking at Config. 3-1 shows that the performance of the barrier system actually decreased slightly overall when a secondary barrier was added with no enclosure absorption. This may have been due to the microphone location being level with the sound source and nearer to the top of the barrier; therefore, the addition of a secondary barrier better trapped the sound within the enclosure, making more sound spill over the top rather than out the bottom. This increase in sound spill over the top would not be preferential for any noise sensitive receivers that may overlook the enclosure.

5.4 Improvements with increased barrier mass

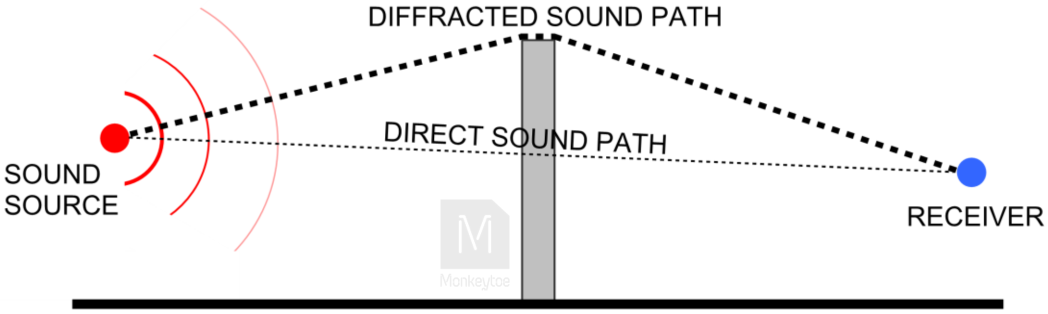
Interestingly, doubling the front barrier mass from 5.4kg/m^2 to 10.8kg/m^2 showed almost no increase in barrier performance. Comparing the barrier's overall performance to the transmission loss performance of the aluminium panel itself (Table 1) indicates that majority of the sound diffracted over the top of the barrier rather than through the panel itself. This suggested the performance of the barrier was limited by the diffraction path instead of direct transmission through the barrier panel.

This implies that increasing the surface mass to increase the transmission loss through a barrier quickly reaches a point of diminishing returns, and that the rule-of-thumb surface weight of 8-15kg/m^2 for a barrier could be unnecessarily high for many real-world applications.

6 BARRIER LOSS ALGORITHM WITH CORRECTION FOR DIRECT TRANSMISSION THROUGH BARRIER

The following section outlines a simple correction to be applied to the typical barrier loss calculation for the case where sound transmission through the barrier may be significant. This could occur, for example, if the barrier is very lightweight and consequently has relatively low transmission loss performance.

A simple barrier loss scenario is depicted in Figure 5.



Source (Chen, K, Beresford, T, 2019)
Figure 5: Simple Barrier Loss Scenario

Giving consideration to the common barrier loss model, where the direct sound propagation from the source is adjusted by the insertion loss of the barrier, the sound pressure level at the receiver location can be modelled as follows:

$$SPL_{receiver} = SWL_{source} - PL - BIL \tag{1}$$

where $SPL_{receiver}$ is sound pressure level at the receiver location
SWL_{source} is the sound power level of the sound source
PL is the direct sound propagation loss from the source to the receiver location,
for example $PL = -10\log\left(\frac{d}{4\pi r^2}\right)$
BIL is the barrier insertion loss

Commonly in this model, the barrier insertion loss considers only the diffracted sound over or around the barrier. The direct sound transmission path through the barrier is ignored because the surface mass of the barrier is assumed to large enough that the direct sound transmission is insignificant. In this case we simply have:

$$BIL = DL \tag{2}$$

where DL is the diffraction loss of sound travelling over/around the barrier.

In the case of a lightweight barrier, however, where the direct sound transmission through the barrier should be considered, it is necessary to modify the barrier insertion loss to also include the transmission loss directly through the barrier:

$$BIL_{mod} = -10log\left(10^{\frac{-DL}{10}} + 10^{\frac{-TL}{10}}\right) \tag{3}$$

where TL is the transmission loss through the barrier material.

This modified barrier insertion loss term, BIL_{mod}, can then be inserted into equation (1) to get:

$$SPL_{receiver} = SWL_{source} - PL - BIL_{mod} \tag{4}$$

6.1 Application of modified barrier insertion loss equation to real-world lightweight barriers

If the modified barrier insertion loss equation is applied to real-world lightweight barriers, the effects of the relatively low transmission loss of such barriers can be investigated.

Taking the measured plant enclosure discussed above (Config. 4) as an example of a typical lightweight barrier system, the transmission loss of the 2mm aluminium barrier material can be included in the calculation, using equation (3), to determine the modified barrier insertion loss:

Table 3: Barrier insertion loss calculation using equation (3)

Octave Band Frequency (Hz)	63	125	250	500	1000	2000	4000
DL, plant enclosure (dB)	4.0	5.0	4.4	10.6	13.0	10.2	12.4
TL, 2mm aluminium* (dB)	12.1	13.3	15.9	20.9	26.0	31.2	32.5
BIL_{mod} (dB)	3.4	4.4	4.1	10.2	12.8	10.2	12.4
$DL - BIL_{mod}$ (dB)	0.6	0.6	0.3	0.4	0.2	0.0	0.0

*Note that the transmission loss values stated here have been obtained from random incidence laboratory measurements, in lieu of normal incidence measurements. It has been assumed that the normal incidence transmission loss values would generally be the same or greater than the stated values.

The last line of Table 3 shows the difference between the diffraction loss over/around the barrier and the modified barrier insertion loss. This is the same as the difference between the unmodified barrier insertion loss (BIL) as described in equation (2) and the modified one (BIL_{mod}) from equation (3). As shown in the table, this difference is relatively small, even for the poor transmission loss values at the low frequencies for the lightweight barrier.

This indicates that there is little decrease in the real-world performance of a barrier if it is of lightweight construction; or in other words, there is little improvement gained in the overall barrier insertion loss, even with significant increases in the surface mass of the barrier material, as illustrated in the table below:

Table 4: Examples of the difference between barrier diffraction loss and modified barrier insertion loss ($DL - BIL_{mod}$) for increasing barrier surface mass in enclosure Config. 4 scenario (dB)

Octave Band Frequency (Hz)	63	125	250	500	1000	2000	4000
2mm aluminium (5.4kg/m^2)	0.6	0.6	0.3	0.4	0.2	0.0	0.0
4mm aluminium (10.8kg/m^2)	0.2	0.2	0.1	0.1	0.1	0.0	0.1
8mm aluminium (21.6kg/m^2)	0.1	0.1	0.0	0.0	0.0	0.0	0.0

7 CONCLUSIONS

The real-world noise barrier performance of various rooftop plant enclosure configurations was investigated through computer modelling and full-scale physical testing. The key findings from this study were:

- The introduction of sound absorption yielded a substantial increase in barrier performance as it reduced the reverberant build-up within the barrier enclosure and limited noise spill out of the enclosure.
- Introduction of a secondary front barrier generally improved barrier performance, where a reduction of the high-frequency noise spill was measured if a combination of absorption and a secondary front barrier was used. If no absorption was present, a slight reduction of performance was measured for microphone positions that were near or above the sound source height.
- Increasing the front barrier surface mass from 5.4kg/m^2 to 10.8kg/m^2 showed very little increase in barrier performance.
- Computer modelling results provided surprisingly poor correlation with the physical test results, where the model significantly over-predicted the performance of the barrier system.
- A simple algorithm was developed to estimate the reduction in performance for lightweight barriers, based on a correction for the transmission loss through the barrier material. This algorithm reinforced the findings about the limited benefit of increasing barrier surface mass in real-world barrier applications.

ACKNOWLEDGEMENTS

We would like to thank the team at Monkeytoe for providing us this opportunity to investigate the performance of lightweight barrier systems in a real-world application. We could not have achieved this without your collaboration and support, thanks again! Also, big props to the Monkeytoe ginger beer brewing team.