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A REVIEW OF RESIDENTIAL BALCONIES WITH ROAD TRAFFIC NOISE

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Abstract

The acoustics of residential balcony spaces in the presence of road traffic noise has been investigated by several authors over a period of several decades. However it would appear there remains an absence of a simple and yet reliable method to predict the acoustics of balcony spaces. There are two primary elements requiring consideration. The first element is to predict road traffic noise levels spatially across the balcony for the function of outdoor noise criteria compliance. The second element is to predict the road traffic noise level on the external facade of the room behind the balcony to assist in the design of facade sound isolation requirements. This paper reviews the methods and results of the key literature available on the acoustic properties of residential balconies in the presence of road traffic noise.

1.0 INTRODUCTION

It is difficult to reduce road traffic noise levels to meet specific criteria in balconies near roads. The use of noise barriers is not feasible for elevated balconies. When the building design is finalised for multi-storey residences, acoustic treatments to the balcony are usually the only remaining option to reduce road traffic noise levels for the private open space of a dwelling. Acoustic treatments to balconies usually consist of solid parapets and acoustic absorption for the ceiling (if present) above the balcony.

The relevancy, practicality and technical performance of these acoustic treatments are usually debated by property developers and acoustic professionals, due to a lack of knowledge in the cost/benefit ratios of the balcony acoustic treatments. Acoustic professionals commonly employ significantly different assessment methods for determining the acoustic effect of balconies (with or without acoustic treatments) on the road traffic noise level on the balcony and also inside the adjacent room. This indicates there is little practical guidance available for acoustic professionals. Some methods observed in use are; (1) to ignore the presence of a balcony altogether; (2) include the edge of the balcony as a barrier edge to provide shielding to a point external to the adjacent room; (3) without justification apply an overall reduction ranging between 3.0 dB(A) to 10.0 dB(A); (4) model a parapet as a noise barrier and use standard barrier attenuation algorithms. These methods ignore the potential for the balcony to amplify noise levels due to increased reflections. Firstly, this paper reviews the possible advantages of balcony treatments. Secondly, a review of the literature available regarding balcony treatments is provided, and finally some general conclusions are made.

2.0 ADVANTAGES OF BALCONY TREATMENTS IN TROPICAL AREAS

Three advantages of providing acoustic treatments to balconies are noted. One is the reduction of spatial variances of road noise within the balcony space. Secondly, to meet internal noise level criteria, the required transmission loss for façade elements is reduced. This imparts construction cost savings. The additional cost of installing the balcony treatments may be balanced by reduced construction costs for the façade. The third advantage is the reduction of internal noise levels for adjacent rooms when the external openings protected by the balcony treatments are opened for natural ventilation. The balcony treatments thus increase the operational flexibility of the adjacent room, and may improve residents' tolerance of the external noise environment. It can be expected that balcony treatments may not provide the attenuations necessary to meet internal noise criteria, however the resulting reductions should be noticeable.

The urban population in Queensland, Australia is mainly in tropical and sub tropical climates located on the east coast of Queensland. These climates allow opportunities for people to enjoy outdoor recreation almost all year. Queensland's climate also promotes natural ventilation as there is generally little need to provide heating or cooling to internal air. Natural ventilation is impeded with standard architectural treatment applied to facades. As a result, road traffic noise attenuation for residential dwellings often impacts the thermal comfort and indoor air quality of the inhabitants. Consequently, both the spatial level variance within the balcony and the effect the balcony has on internal noise levels have equal importance.

3.0 RESEARCH REVIEW

This review of the available literature is presented in the chronological order of publication. This allows the reader to observe the research and technology trends over time.

Gustafsson and Einarsson [1] reviewed gallery houses, where the balcony was a semi-enclosed type with a solid parapet. The effect of road traffic noise reduction was considered dependent on five variables; (1) the height of the barrier; (2) the height of the opening between the parapet and the ceiling; (3) the depth of the balcony; (4) the sound absorption of the ceiling and; (5) the direction of the incident sound. Measurements were conducted at three locations, one external and two inside adjacent rooms on ground and first floor levels. The measurements indicated a solid parapet and highly absorptive treatment on the ceiling increased internal noise reductions by 4.5 dB(A) compared to no parapet or absorption.

Mohsen and Oldham [2], raised the concept of "self protecting" buildings and investigated the effect of balconies on the transmission loss required for an adjacent room using a computer model and a 1:10 scale model. The computer model predicted the change in intensity over the aperture, not spatially over the balcony. The computer model assumed; (1) the source is near the ground and the ground is perfectly reflecting; (2) the source is broad band and consequently there were no interference effects due to the ground reflection; and (3) the balcony acts a barrier to the direct field. With the scale model, the full scale room reverberation time was 0.5 seconds and the microphone was 1.0 m high representing a seated person. Overall, 270 geometrical configurations were measured with four balcony configurations, three windows types, five source positions, three building orientations and 5 different measurement positions within the room. The calculated average attenuation at the building facade was correlated with the spatial average of measured attenuation inside the room. Table 1 summarises the results. The authors concluded that prediction to the open aperture can be correlated to an internal noise level reduction, relatively regardless of the geometry configuration. The attenuation measured in the room was generally less than the predicted attenuation at the facade. The effect of a balcony on the variability of road traffic noise was also assessed using a predicted cumulative noise level distribution, with and without a balcony. The distribution curve was steeper in the presence of a balcony which indicated the balcony reduced noise level and also the level variability. The results are limited to balconies without a ceiling.

Table 1: Summary of results from Mohsen and Oldham [2]

Data Location	Attenuation
Calculated Attenuation at Facade (dB(A))	0 to 14 (No amplification of noise was predicted at the facade.)
Measured Attenuation within Room (dB(A))	-0.5 to 11 (Some amplification was measured within the room for some configurations)

May [3] compared measured noise levels (from a freeway) on high rise balconies with solid parapets and ceilings and at ground level where the intervening ground was absorptive (not a built up urban area). Noise level variability with height above the balcony floor was also measured. The effects within an adjacent room were not considered.

In his study, noise levels at the centre of the balcony were measured and compared to a normalising reference position approximately 2.4 m outside the balcony. The balconies were 40 m to 80 m from a freeway. For a 17th floor balcony, the noise level above the balcony floor increased by around 3.0 dB(A)/m, however the data suggests a linear trend is an oversimplification as a linear trend does not account for localised shielding effects of the parapet. Near the balcony ceiling, the noise level was around 7.0 dB(A) above the reference position. Near the balcony floor the noise levels were similar to the reference position level. Next, the effect of three absorption treatments was measured. The first treatment was on the ceiling only which provided a mean reduction of 5.4 dB(A). The second treatment was on the ceiling and back wall which provided a mean reduction of 8.0 dB(A). The third treatment was all internal faces within the balcony which provided a mean reduction of 11.3 dB(A). Providing absorption within the balcony provided a high level of L_{Aeq} reduction. The author suggested the diffuse field sound reduction from absorptive treatments can be estimated by a logarithmic ratio of total absorption, before and after treatment. Finally, the study concluded that due to reducing ground absorption, road traffic noise levels increase for higher floor levels of high rise buildings, and can be up to 10 dB(A) greater than at ground floor.

Oldham and Mohsen [4] continued the focus of "self protecting" buildings (like, [2]) for reducing internal noise levels whilst still allowing for natural ventilation. A computer model was developed which considered a direct path and a first order fully specular reflection from the ground plane. The computer model calculated external attenuation over the weak element of the façade by the difference between unscreened and screened intensities. The variables considered important were the effective height of the parapet; the window size (2.0 m^2); the shape of the window ("square", "vertical" and "horizontal"); and the dimensions of the adjacent room (3.0 m × 4.0 m × 2.8 m). A 1:10 scale model was used to measure inside the adjacent room. An open and closed balcony was investigated over three different floor heights with source distances at 7.5 m or 12.5 m. The results suggested, with increasing floor level the rate of calculated external attenuation increased faster than the rate of measured internal attenuation. Conversely with increasing distance, the rate of measured internal attenuation increased faster than the rate of calculated external attenuation. The authors then generated cumulative distribution curves where screening was observed to significantly reduce the variability of the road traffic noise. It was also discovered that increasing the length of the balcony did not change the cumulative distributions significantly, as the highest level contributions are from the relatively few sources that are perpendicular to the facade (that is; the sources with the closest distance to the receiver). The study did not consider reflections from opposite facades, nor the ceiling of a balcony.

Tzekakis [5], like [2] and [4] mentioned that the attenuation provided by balconies may be useful in improving the availability of natural ventilation but also added that in warmer climates, outdoor semi-enclosed living spaces are desirable and also improve sun protection to the dwelling. The author measured L_{Aeq} spatial differences in the acoustic field within and part way into an adjacent room of a 3rd floor balcony, 11.6 m above the road, located in a narrow built up street approximately 15 m wide. Similar to [3], one microphone was fixed at a normalising reference location (distance from parapet not reported), and a second microphone was used to measure spatially. The author did not provide consideration whether the reference position was free field or influenced by the facade. Seven cases were measured, with six different acoustic treatments. Table 2 summarises the results, where the highest level of treatment provided a 4 to 5 dB(A) reduction which is similar to the measured reductions of [3] for a similar acoustic treatment.

Table 2: Measured attenuation, Balcony (Upper and Lower Zones), Results from Tzekakis [5]

Acoustic treatment case description	Upper	Lower
1. Balcony without any modifications (open door).	-	-
2. Solid parapet, 0.88 m high.	3 dB(A)	5 dB(A)
3. A horizontal extension, 0.40 m out from the top of the solid parapet in Case 2.	3 dB(A)	5 dB(A)
4. One absorbing strip to ceiling without a solid parapet.	1 dB(A)	2 dB(A)
5. Two absorbing strips to ceiling without a solid parapet.	2 dB(A)	2 dB(A)
6. As per case 5 but with one absorbing strip to the ceiling inside the room.	2 dB(A)	3 dB(A)
7. All measures combined, Cases 2 to 6.	4 dB(A)	5 dB(A)

Hammad and Gibbs [6] used a 1:10 scale model (similar to [2, 4]) to measure the protection inside the adjacent room provided before and after installing different balcony types. The attenuation results for a balcony (no parapet) with absorptive ceiling and absorptive full height side walls of variable depth are summarised in Table 3 and Table 4.

Table 3: No parapet, absorptive ceiling and side walls, from Figure 2 in Hammad and Gibbs [6]

Floor	Depth	Attenuation characteristics, dB	Frequency
1st Floor	1 m	~ 5 dB, 250 Hz to 4 kHz	Invariant
3rd Floor	1 m	~8 dB, 250 Hz to 4 kHz	Invariant
5th Floor	1 m	~10 dB, 250 Hz to 4 kHz	Invariant
1st Floor	4 m	~10 dB, 250 Hz to 4 kHz	Invariant
3rd Floor	4 m	~8 dB at 250 Hz, increasing ~3 dB per octave up to 4 kHz	Dependent
5th Floor	4 m	~10 dB at 250 Hz, increasing ~3 dB per octave up to 4 kHz	Dependent

Table 4: No parapet, absorptive ceiling and side walls, from Figure 4 in Hammad and Gibbs [6]

Balcony Depth	1 m	2 m	3 m	4 m
1st Floor	1 dB(A)	4 dB(A)	6 dB(A)	10 dB(A)
2nd Floor	2 dB(A)	6 dB(A)	11 dB(A)	15 dB(A)
3rd Floor	6 dB(A)	12 dB(A)	15 dB(A)	16 dB(A)
4th Floor	8 dB(A)	10 dB(A)	16 dB(A)	20 dB(A)
5th Floor	5 dB(A)	11 dB(A)	14 dB(A)	18 dB(A)

Table 5: Additional attenuation from 1.0 m parapet and 0.5 m ceiling shield, from Figure 7 in [6]

Balcony Depth	1 m	4 m
1st Floor	5.0 dB(A)	6.0 dB(A)
2nd Floor	5.0 dB(A)	8.0 dB(A)
3rd Floor	5.5 dB(A)	2.0 dB(A)
4th Floor	5.0 dB(A)	0.0 dB(A)
5th Floor	3.0 dB(A)	2.0 dB(A)

A balcony with variable depth with ceiling and full height side walls and a 1.0 m high parapet and 0.5 m high ceiling shield was modelled. The extracted results are summarised in

Table 5. The additional attenuation was reasonably constant for a 1 m balcony depth, while it is variable at a 4 m balcony depth. Additional attenuation at lower floors was a result of interference with line of sight and the direct path. The effect of the solid parapet diminishes at higher floor levels and deeper balconies, because the additional path difference due to the solid parapet also diminishes. They also found the provision of semi-permeable screens above parapets increased the shielded area of the reflective surfaces within the balcony space, hence attenuation increased.

Hothersall et al., [7] developed a two dimensional boundary element model capable of calculating interference and standing wave effects to predict noise level at the centroid of four, 1.0 m deep balconies with a parapet. Each balcony was 6.5 m from the source and 4.5 m, 7.5 m, 10.5 m and 13.5 m above the source. Reference receivers were 1.0 m away from the parapet. Results were calculated for $1/9^{th}$ octaves between 58 Hz and 3415 Hz and presented as a level difference, which was the predicted level with the road and building present less the free field level. The insertion loss of an acoustic treatment was the difference between the predicted level with the treatment less the predicted level with rigid walls. The various absorption treatments modelled were, (*a*) ceiling; (*b*) parapet inner face; (*c*) parapet outer face; (*d*) façade; (*e*) absorption as per (a) and (b); (*f*) absorption as per (a), (b) and (c); (*g*) absorption as per (a) and (d); and finally (*h*) absorption as per (a), (b) and (d). The mean change in level due to the insertion of the rigid surfaces compared to pure free field levels was close to 6.0 dB(A) for both reference receivers and balcony receivers. For the balcony receivers, treatment (a) to the ceiling provided a mean insertion loss of 6.3 dB(A). The mean insertion loss for balconies at 4.5 m and 7.5 m above the road surface (Floors 1 and 2) was 5.0 dB(A). Treatment (h) to all internal balcony surfaces (except the floor), provided a mean insertion loss of 7.5 dB(A) (approximately 5.5 dB(A) at Floors 1 and 2 and 9.5 dB(A) at Floors 3 and 4). The highest insertion loss measured was 10.0 dB(A) for treatment (f). The introduction of absorption treatment reduced the level of narrow frequency band peaks in mid to high frequencies (> 500 Hz). A law of diminishing returns was noticed with absorption treatments, as there was only 2.7 dB(A) extra attenuation from case (f) to case (a).

Cheng et al., [8] conducted a study involving theoretical prediction, a 1:10 scale model and a 1:1 scale model where the focus was horizontal screens near the window to provide attenuation. The effect of inclining the underside of a horizontal screen above a receiver was found to provide an additional noise reduction of between 0 dB(A) and 3.0 dB(A) through a range of ceiling inclinations, 0º to 90º. It was determined that the most efficient reduction for least angle of screen inclination was at 30º inclination.

Kropp and Berillon [9] developed a three dimensional theoretical model and a 1:10 scale model to verify the theoretical model. The balcony dimensions were 2.7 m high, 2.7 m long and the depth was 1.35 m with an absorptive ceiling. The source distance was 30 m and 25 m below the balcony floor. At frequencies below 100 Hz, a balcony without a parapet was found to amplify sound energy within the balcony space. A 1.0 m high parapet increased the amplification below 50 Hz. The theoretical model was extended to include an adjacent room, and balconies with and without absorption on the ceiling and facade. With balcony absorption, the overall insertion loss in an adjacent room at 4.0 m above the source was 6.0 dB(A) and 11.0 dB(A) at 25.0 m above the source. The balcony without absorption was found not to provide any attenuation, and amplification was predicted below 50 Hz for balconies with and without absorption. These results showed that the ceiling absorption has greater effect when the balcony is elevated high against the source position and less effective when the source and balcony are on similar elevations.

European Standard EN 12354-3:2000 [10] defines a calculation model for the prediction of internal noise. One variable included is the "Façade shape level difference ΔL_{fs}", which is defined such that ΔL_{fs} is 0 dB for a plane façade. The correction term ΔL_{fs} can be used for internal noise predictions as it adds to the apparent sound reduction index. This standard does not attempt to provide indication on the spatial levels within a balcony space. The suggested values of ΔL_{fs} in Figure C.2 in [10] range from -1 dB (lintel/screen above receiver/shallow balcony with no absorption) to 3 dB (shallow balcony with parapet and high grade ceiling absorption) and 4 dB (deep balcony with parapet and high grade ceiling absorption).

Li et al., [11] aimed to develop a simple prediction method by adapting the CoRTN [12] algorithms with ray tracing for noise within balcony spaces and against the façade. Measurements were made on actual balconies like [1, 3, 5]. These measurements were near the balcony centre and at the façade and at different heights above the floor to verify predictions. Similar to [3, 5] a control point, assumed free field, was established at 1 m outside the balcony. The predicted insertion loss was 0.5 to 3.0 dB(A) above the measured at 1.5 m and 2.0 m above the floor. Just above the floor, the predicted and measured insertion loss difference was around 6.0 to 7.0 dB(A). When there is no balcony ceiling, the predicted levels correlated reasonably well with measured levels. These results indicated that a simple prediction method would not be sufficiently accurate enough for all balcony types and acoustic treatments. Table 6 shows the mean ($\bar{x}$) measured insertion loss results. It is noticed that the insertion loss decreases by around 3 dB(A) per metre with height above the floor, which is a similar result to that measured by May [3]. The overall mean measured insertion loss is 5.2 dB(A) at the façade and only 2.0 dB(A) at the centre of the balcony.

Table 6: Measured insertion loss ($\bar{x}$), from Figure 8 and 9 from Li et al., [11]

Site	Floor Level	Centre of the balcony					Façade of a balcony				
		Height above floor, m					Height above floor, m				
		0.5	1.0	1.5	2.0	$\bar{x}$	0.5	1.0	1.5	2.0	$\bar{x}$
1	3	4.5	3.0	0.0	-0.5	1.8	6.5	5.0	3.8	2.0	4.3
1	4	5.0	3.5	1.0	0.0	2.4	7.5	5.5	5.8	5.0	5.9
1	5	6.0	5.0	1.0	-0.5	2.9	8.0	7.0	5.0	4.0	6.0
$\bar{x}$ Site 1		5.2	3.8	0.7	-0.3	2.3	7.3	5.8	4.8	3.7	5.4
2	5	2.0	1.5	-1.0	-1.0	0.4	3.5	3.0	2.0	1.0	2.4
2	9	3.0	3.0	0.0	-1.0	1.3	7.0	6.5	5.5	2.0	5.3
2	11	6.5	6.0	1.5	0.0	3.5	9.5	8.8	6.3	5.0	7.4
$\bar{x}$ Site 2		3.8	3.5	0.2	-0.7	1.7	6.7	6.1	4.6	2.7	5.0
$\bar{x}$ (Site 1 and 2)		4.5	3.7	0.4	-0.5	2.0	7.0	6.0	4.7	3.2	5.2

Hossam El Dien and Woloszyn [13] investigated the effect of an inclined balcony ceiling, similar to [8], at various angles of 5º, 10º and 15º on noise at the façade using a pyramid ray tracing model. The study included 17 floor levels with different balcony widths (1, 2, and 3 m), all at 8 m to the source. The protection level was the difference in predicted level between a flat ceiling (0º inclination) and the inclined ceiling. The effect of an inclined ceiling was not noticeable at floor levels below the 4th floor as the direct component dominated. With 2 m and 3 m balcony depths, the inclined ceilings provided amplification. Above the 4th and 5th floors, attenuation on average was around 1 dB(A). From 0.3 m to 2.2 m above the floor, the average attenuation decreased from 3.0 dB(A) to 0 dB(A). On average, the 5º inclined ceiling was predicted to provide higher protection levels than 10º or 15º.

The authors continued to investigate, [14], the effect of noise level at the façade with various balcony depths and inclined parapets with angles of 15º and 30º. Predictions were carried out using a pyramid ray tracing technique, as per [13]. A 1:10 scale model, like [2, 4, 6, 8, 9], was used to measure in the façade plane to verify the predicted results. The predicted protection levels were always greater than the measured, however the difference narrowed with increasing floor level. The protection values of a 1 m deep balcony ranged from 4.0 dB(A) to 7.0 dB(A). The 2 m deep balcony slightly reduced the protection level compared to a 1 m deep balcony due to the increase in reflected surfaces, but overall produced similar protection levels of 4.0 dB(A) to 6.0 dB(A). Similar results also occurred for the 3 m deep balcony. Inclining the parapet 30º provided 0.5 to 2.0 dB(A) for a 1 m depth, 2.0 to 3.0 dB(A) for 2 m depth and 2.0 to 3.0 dB(A) for a 3 m depth. The protection level generally increased with height above floor as the inclined parapet increased the shadow zone on the facade. The reduction obtained from inclined parapets appeared similar to reductions provided by absorption treatments determined by others [3, 6, 7].

Tang [15], like [2, 4, 6, 8, 9, 14], used a 1:10 scale model to study the acoustic protection to the façade offered by a balcony array consisting of nine equi-spaced balconies without absorption in a 3 × 3 matrix. Four different balcony types were considered; (1) "Closed" – parapet on front and both sides; (2) "Front-bottom" – parapet on front only; (3) "Side-bottom" – parapet on sides only; and (4) "Bottom" – no parapets. Spectral measurements at 25 locations in the plane of the façade were conducted in the middle column balconies. As with [2], [4] and [8], the angle of incidence was used as a variable to correlate results. The distance to the source was 5 m to 20 m in full scale. The insertion loss was the reduction in level after the installation of the balconies. Overall noise level results indicate the Closed type provided the largest insertion loss. The Bottom type provided the least insertion loss. With a ceiling present, amplification was observed at heights 2.0 m and more above the balcony floor. When there was no ceiling, mostly positive insertion losses were observed for all heights above the balcony floor and for all balcony types. For all balcony types the range of insertion losses were -1.0 dB(A) to 9.0 dB(A), with the Closed balcony configuration providing the most consistently high insertion loss. It was observed that the higher attenuation for the Closed and Front-bottom balconies indicated that the solid side parapets provide more diffraction attenuation than reverberation amplification.

At 5 m to the source, the balcony type did not affect the spectral insertion loss when the distance to the source was small. The insertion loss was around 6.0 dB broad band for all balconies without a ceiling. With a ceiling and small source distance, 2.0 dB to 4.0 dB amplification occurred at most frequencies below 400 Hz and above 680 Hz.

At 10 m to the source, balconies without a ceiling and with a parapet experienced significantly lower broad band attenuation (~2.0 dB) than the broad band attenuation (~5.0 dB) for balconies without a parapet. With a ceiling, balcony type did not appear to affect the insertion loss on a frequency basis. There was an increase in the number of frequencies where attenuation was measured, and also an increase in the insertion loss in these frequencies compared to the 5 m source distance. At the 1st floor, there was a significant increase in the attenuation in frequencies centred around 1000 Hz. Similar results were found for full scale distances of 20 m as found with the 10 m distance. With increasing source to receiver distance, the insertion losses in mid to high frequencies were found to increase.

Table 7: Summary of results from Lee et al.,[16]

Treatment Description	Results of the Treatment
0.5 m or 1.0 m lintel; 0.5 m or 1.0 m parapet	Amplification due to increased ceiling reflection area. Attenuations ranged between -1.0 dB to 5.7 dB.
15º inclined ceiling	Amplification up to floor 6, from floors 7 to 15 range of attenuation was 2.1 to 8.8 dB with mean values of 5.4 dB.
15º inclined absorptive ceiling	Attenuation at all floors except 2nd. Average reduction for all floors is 5.9 dB.
0.5 m or 1.0 m parapet with an absorptive 15º inclined ceiling	Attenuation at all floors. Average reduction for all floors is 10.0 dB. Attenuation is generally between 10.0 dB and 15.0 dB at 1 kHz and generally between 5.0 dB and 10 dB at 500 Hz.
0.5 m or 1.0 m parapet with absorption on the internal face and an absorptive 15º inclined ceiling	Attenuation at all floors. Average reduction for all floors is 11.5 dB. Attenuation is generally between 10.0 dB and 15.0 dB at 1 kHz and generally between 5.0 dB and 10 dB at 500 Hz.

Lee et al., [16] studied attenuation provided at the building façade (1.5 m above the floor) by various balcony types in high rise residential building complexes with a 1:50 scale model. The treatments considered a solid parapet, screen (similar to [8]), absorber and inclined ceiling (similar to [8] and [13]). By measuring the noise level on balconies facing a 6 lane road at floors 1 to 5 inclusive, 7, 9, 11, 13, and 15, they found similar to the results of [3] where road traffic noise levels increased with increasing floor height up to around the 10^{th} floor level. Six different balcony treatments were investigated. The balcony dimensions were 1.2 m deep, 4.5 m long and 3.0 m high. The balcony treatments and results are presented and described in Table 7. It was found that a combination of treatments including ceiling absorption would provide attenuation at all floor levels.

4.0 CONCLUSIONS

The importance of reducing road traffic noise levels to residential balcony spaces has been identified. Several benefits of acoustic treatments have been highlighted broadly as a spatial reduction within the balcony space and also reducing the internal noise level in an adjacent room. There is a reasonably large range of research completed in this area, and this has been concisely summarised. The research has involved a range of methods from full scale measurements in [1, 3, 5, 11, 16] to scale modelling in [2, 4, 6, 8, 9, 14-16] and theoretical models in [2, 4, 7-9, 11, 13, 14]. It is clear from the research, that significant acoustic benefits can be achieved through the use of acoustic treatments on balconies, both spatially on the balcony and internally. However more research appears necessary to consolidate and focus this topic into pragmatic design guides and training for use by acoustic professionals.

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