Sydney Opera House

Lower Concourse DA

Operational and Construction Noise Impact Assessment

Rev 4 | 5 August 2019

Job number 245827

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Contents

1 Introduction

This report presents the results of an assessment of noise from consolidated existing operational uses and minor works on the Lower Concourse for the Sydney Opera House (SOH). This report is intended to support the DA submission and documentation for the Environmental Impact Statement.

A glossary of acoustic terminology has been included in Appendix B.

1.1 Scope of Assessment

This assessment reviews operational and construction noise issues for the following proposed components of the development:

- Extension and realignment of an existing glass line to enclose the underutilised area between the main Opera Bar restaurant and the Meat and Cheese Room;
- Replacement of 16 existing umbrellas outside the Opera Bar and Opera Kitchen with improved shade covers;
- Refurbishment of an existing back of house area to create a new office and cool room for the Opera Bar; and
- Consolidation of all uses within the Lower Concourse area within a single consent

2 Executive Summary

The use of the Lower Concourse in its current manner is compatible with the Sydney Opera House precinct and supports the Opera House as a performing arts venue, contributing to the recreational, cultural and tourism attributes of the area.

The Noise Impact Assessment demonstrates the uses of the Lower Concourse have no adverse impact on the amenity of neighbouring properties and the surrounding area.

Noise generated by live and recorded music is managed through the design of the system itself and by controlling the hours of operation. The amenity impacts from patrons coming and going to the premises are managed through the existing management plans required under the liquor licences.

Patron numbers are managed in accordance with the venue liquor licences and management plans.

A development consent for licensed premises may typically contain conditions of consent for specific matters such as hours of operation, maximum capacity, noise mitigation. It should not cover matters that will be covered in a liquor license, for example, conditions that relate to the responsible service of alcohol, requirements to have security guards and requirements to have closed circuit televisions operating.

2.1 Operational Noise

The proposed upgrades are not expected to result in any increase in noise from normal operation compared with current conditions. No changes in plant are proposed so that there would be no changes in plant noise.

2.2 Construction Noise

Most of the construction works for the project are external but shielded by the upper concourse. Full height hoarding will be set in place to enclose work areas below the upper concourse; as such, some external spaces will be temporarily enclosed and become internal spaces during the construction process (e.g. the extension and realignment of an existing glass line).

The assessment of construction noise has been based on worst-case assumptions (5 sets of impact drills being used continuously and concurrently). Under these worst-case conditions and with some operations being screened by the upper concourse, the predicted noise levels are 3dB over the ‘noise affected level’. This is a negligible exceedance given the pessimistic assumptions made.

Notwithstanding the above, the Sydney Opera House (SOH) has recognised noise issues affecting nearby neighbours during external construction works in the past. Therefore, the SOH intends that contractors who are undertaking noisy external works identify mitigation measures for this work in their Construction Noise Management Plan (CNMP) which they will be required to prepare before work

starts on site. This CNMP will be reviewed by the SOH and their noise consultants prior to approval and implementation on site.

The Contract with the Managing Contractor will include a clause allowing SOH to disallow any equipment that it considers to be excessively noisy. Similarly, the Managing Contractor may include incentives, as it sees fit, for sub-contractors who can provide noise mitigation measures as part of their contract works.

Should complaints be received, attended acoustic monitoring will be undertaken to ascertain the 'noisier' work activities and address specific work practices and locations to better alleviate noise complaints from that particular activity.

Following identification that all noise levels have returned to being consistently below the above maximum levels, the monitoring will revert to remote monitoring.

Nearby residents will be provided with a notice that informs them of the nature of the works, the duration and the extent of works being undertaken. Contact details will be provided to allow complaints to be logged and addressed as soon as possible by the Opera House.

3 Development Description

3.1 Proposed Uses

It is proposed to consolidate all the uses on the Lower Concourse under one planning consent. These uses include food and beverage venues (trading as Opera Bar and Opera Kitchen) and the Welcome Centre.

Opera Bar is a licenced premise with capacity for up to 1,800 patrons. The premises are expected to hold catering of food and beverage and host events with live music.

Opera Kitchen is a licenced premise with capacity of 570 patrons. Live music is not permitted at the Opera Kitchen, and it is not expected that the uses include live music performances. Background music is played throughout the venue via a public address (PA) system.

The Welcome Centre is located on the north end of the lower concourse. No live music or PA system is expected to be part of this space.

3.2 Construction activities

The exact construction techniques and equipment will be finalised by the eventual contractor(s) for the project. Based on the best information available, the following are likely to be involved.

- Cutting in a new doorway,
- Realigning the existing glazing,
- Installing new shade sails.

Construction noise will be managed by long-established construction work practices on site including restriction of noisy work hours and hoardings around work sites.

More detail is given in Section 7.1 of this report. Some works will need to be done outside of normal working hours because of the sensitivity of the internal spaces within the Opera House.

4 Existing Environment

The NSW Noise Policy for Industry (NPI)[1] sets out a methodology to characterise the background noise environment at a proposed development and to derive appropriate criteria for noise from plant affecting the environment.

This is based on the levels of existing noise at sensitive receivers located around the site which in turn are derived from an extensive survey of existing ambient noise levels. Methods outlined within the NSW NPI were used to measure and derive the Rating Background Level (RBL). Subsequent noise criteria for different applications were then derived based on the RBL data as presented in Section 4.4.

Further details of the noise surveys carried out are provided in Appendix A.

4.1 Description of Site

The site is located on the Bennelong Point peninsula in Sydney Harbour and is near to a major passenger ferry terminal, Circular Quay - a lively area with pedestrian noise, outdoor restaurants and buskers. Ferry noise is distinctly audible from 5am to 1am. Aircraft noise from low lying helicopters, commercial seaplanes and passenger aircraft can be heard from time to time.

The area around the SOH is effectively pedestrianised although there are some occasional deliveries and drop-offs that visit the southern end of the site. Deliveries are generally via the underground loading dock at the southern end of the site. Most of the traffic visiting the site accesses the adjacent car parking via an underground route.

The site is characterised by general pedestrian activity and noise from the harbour activity, with occasional aircraft movements. The background noise environment also contains traffic noise from the Cahill Expressway (located to the south and west on the Harbour Bridge) and rail noise from the Harbour Bridge (located to the west).

The SOH is a world heritage building and an iconic Sydney landmark located within a vibrant urban environment. The Opera House site has a long history of operating community and ticketed outdoor events. Such events are held on the nearby Forecourt, Monumental Steps and Western Broadwalk.

4.2 Noise Sensitive Receivers

The nearest residential noise sensitive receivers located at 1 Macquarie Street, Sydney are shown in Figure 1.

The next nearest residential receivers are the Kirribilli apartments, located around 700 m across the harbour to the north of the site.

[1] NSW Noise Policy for Industry. Environment Protection Authority. January 2017

Figure 1: Noise sensitive receivers (image courtesy of Google Maps)

4.3 Measurement of existing noise levels

Surveys of the existing noise levels at the nearest noise sensitive receivers have been conducted by various parties[2,3] (including Arup).

Unattended noise logging measurements by Auditoria were undertaken to determine the noise levels at the Bennelong Apartments, East Circular Quay on Levels 4 and 9.

Further details of the noise surveys carried out are provided in Appendix A.

[2] Sydney Opera House. Acoustic Assessment for Modification of DA-445-10-2003. Acoustic Studio. August 2016
[3] Acoustic Assessment- Proposed Amendments to The Opera Bar Lower Concourse Restaurant Area. Report by The Acoustic Group. 15 March 2017

4.4 Background Noise Levels

4.4.1 External noise level

Single-number background noise measurements ($L_{A90,15min}$) determined using the "tenth percentile" method and time periods as per the NSW Industrial Noise Policy) are summarised in Table 1. Refer to Appendix A for further details.

A customised Rating Background Level (RBL) has also been derived using only 10pm – 12am measurement data at Bennelong Apartments receivers to represent a 'worst case' (i.e. lowest background noise) condition that may occur during the typical operating time limits assumed for activities in the Lower Concourse.

Table 1: Background noise levels at noise sensitive receivers, dB re 20µPa

Receiver	Period	Time	Rating Background Level, $dBL_{A90,15min}$									
			dB(A)	Octave Band Centre Frequency, Hz[1]								
				31.5	63	125	250	500	1k	2k	4k	8k
Boundary of Bennelong Apartments	Day	7:00am to 6:00pm	58	65	63	60	56	54	53	51	47	41
	Evening	6:00pm to 10:00pm	57	63	64	58	53	52	51	51	48	43
	Night[2]	10:00pm to 12:00am	56	66	64	59	55	54	52	46	38	30
	Night	12:00am to 7:00am	48	58	56	51	47	46	44	38	30	22

[1] Octave band centre frequency has been scaled to the derived RBL for each period based on attended measurements carried out on ground floor outside of the Bennelong apartments during a representative 15-minute period within the period

[2] Period considered 'worst case' (i.e. lowest background noise) condition that may occur during the typical operating time limits assumed for uses within the Lower Concourse

4.4.2 Internal noise level

Attended measurements undertaken by The Acoustic Group at the Bennelong Apartments are presented in Table 2.

The measurement is described as follows:

"*(…) Inside the apartment the ambient level was in the order of 32 dB(A).*

At about 8:35pm the band commenced and was faintly audible inside the apartment and indicates a slight increase in the ambient noise levels both internally and externally.

The ambient background level in the apartment with the doors closed was determined by the noise from the ventilation exhaust system in the kitchen, being a part of the ventilation system for the entire building. An inspection of the living room revealed a number of small vertical windows in the external façade and a side door to the balcony of which the seals for the door and the vertical windows were leaking giving rise to some intrusion of music that could be detected at the dining room area but no transmission of music via the balcony door."

Table 2: Internal background noise levels at noise sensitive receivers, dB re 20µPa

Receiver	Period	Time	Background Level, $dBL_{A90,15min}$									
				Octave Band Centre Frequency, Hz[1]								
			dB(A)	31.5	63	125	250	500	1k	2k	4k	8k
Inside Bennelong Apartments	Evening	8:30pm	32	53	42	36	31	30	25	18	12	12

5 Noise Criteria

5.1 Operational Noise

5.1.1 Plant Noise Criteria

No changes to the existing mechanical or electrical services plant equipment servicing the Lower Concourse are expected to take place as part of the upgrade works. We are not aware of any issues associated with noise from fixed plant.

No further review of industrial noise sources is considered as part of this assessment.

5.1.2 Noise from Lower Concourse activity

There are successful existing precedents regarding noise limits from the uses of the SOH Lower Concourse as defined in the approved Conditions of Consent from previous Key Liquor licences[4,5]. The Licences set out various noise criteria which are shown below. These limits are used as a reference for assessment against within this report.

Opera Bar

The NSW Independent Liquor and Gaming Authority states in *Key liquor licence details recorded as at 21 October 2016* (Licence number: LIQO600779774) the following under condition reference 3040:

> *The LA10 noise level emitted from the licensed premises shall not exceed the background noise level in any Octave Band Centre Frequency (31.5Hz – 8kHz inclusive) by more than 5dB between 07:00 AM and 12:00 midnight at the boundary* of any affected residence.*
>
> *The LA10 noise level emitted from the licensed premises shall not exceed the background noise level in any Octave Band Centre Frequency (31.5Hz – 8kHz inclusive) between 12:00 midnight and 07:00 AM at the boundary* of any affected residence.*
>
> *Notwithstanding compliance with the above, the noise from the licensed premises shall not be audible* within any habitable room in any residential premises between the hours of 12:00 midnight and 07:00 AM.*
>
> *Interior noise levels which, although restricted in accordance with the above condition, still exceed safe hearing levels, are in no way supported or condoned by the Authority.*

[4] Key liquor licence details recorded as at 21 October 2016; Licence name: Opera Bar; Licence number: LIQO600779774, NSW Independent Liquor and Gaming Authority
[5] Key liquor licence details recorded as at 21 October 2016; Licence name: Opera Kitchen; Licence number: LIQO660033112, NSW Independent Liquor and Gaming Authority

**For the Bennelong Apartments the above noise condition criteria is to be applied inside any habitable spaces in the building complex with doors and windows closed and mechanical ventilation in operation*

Opera Kitchen

There are no conditions related to noise criteria for the operation of the Opera Kitchen however, condition reference 3060 of *Key liquor licence details recorded as at 26 October 2016* (Licence number: LIQO660033112) states:

Neighbourhood Amenity

The management of the premises:

i. Shall ensure patrons do not crowd or loiter in the vicinity of the premises in such manner that pedestrian movement is obstructed or hindered.

ii. Shall ensure that the manner in which the business of the premises is conducted and/or the behaviour of persons entering and leaving the premises does not cause undue disturbance to the amenity of the neighbourhood. In this regard, the management shall be responsible for the control of noise and litter generated by persons and/or premises operations. If so directed by Council, the Management is to employ private security staff to ensure that this condition is complied with.

iii. Shall record in a Register full details of any disturbance complaint/s made by a person to management or staff in respect to the manner in which the business of the premises is conducted and/or the behaviour of persons entering or leaving the premises. Such recording will include time, date, nature of the complaint/s and any complainant details if provided.

iv. Shall respond to any disturbance complaint/s in a timely and effective manner. All actions undertaken by management / staff to resolve such complaint/s shall be recorded in the Register. An adequate queuing system for patrons must be implemented at the main entrance of the licensed restaurant so as to ensure that if patrons are queuing to gain entry they do not obstruct or impede pedestrian traffic flow.

Welcome Centre

The Development Consent (SSD 6353) under condition F5 Noise control – General states:

Noise associated with the use of the building including any mechanical plant and equipment shall not give rise to any one or more of the following:

(1) Transmission of an 'offensive noise' as defined in the Protection of the Environment Operations Act 1997 *to any affected receiver; and*

(2) A sound pressure level at the boundary of any affected receiver that exceeds the background ($L_{A90,15minutes}$) noise level by more than 5dB.

The background noise level must be measured in the absence of noise emitted from the use in accordance with Australian Standard AS1055

5.1.3 Project specific operational noise criteria

The criteria relevant to the operational uses of the lower concourse is summarised in Table 3.

It is noted the criteria for the Bennelong apartments is applied *inside* any habitable spaces in the building complex *with doors and windows closed and mechanical ventilation in operation*. However, the criteria presented in Table 3 are provided as indicative criteria for assessment purposes.

Background noise levels *inside* the Bennelong Apartments are given in Table 2.

Table 3: Project specific operational noise criteria

Receiver – Bennelong apartments	Period	Time	Sound Pressure Level at receiver, dBL$_{A10,15min}$									
				Octave Band Centre Frequency, Hz								
			dB(A)	31.5	63	125	250	500	1k	2k	4k	8k
Building boundary	Day	7:00am to 6:00pm	63	70	68	65	61	59	58	56	52	46
	Evening	6:00pm to 10:00pm	62	68	69	63	58	57	56	56	53	48
	Night[1]	10:00pm to 12:00am	61	71	69	64	60	59	57	51	43	35
	Night[2]	12:00am to 7:00am	48	58	56	51	47	46	44	38	30	22
Inside	all times[3]	N/A	58	47	41	36	35	30	23	17	17	58

[1] Night-time period is separated into 10:00pm to 12:00am and 12:00am to 7:00am as Liquor Licence provides criteria for the night-time period before and after midnight.

[2] Notwithstanding compliance with the night-time criteria, the noise from the licensed premises shall not be audible within any habitable room in any residential premises between the hours of 12:00am and 07:00am

[3] These are based on the measured internal background noise levels which are assumed to be dominated by plant noise and therefore not affected by time of day. The measured data is given in Table 2. The criteria for operation up to 12:00am are based on the measured level L_{90}+5dB

5.2 Construction Noise Criteria

This report only considers impacts on receivers external to the SOH from construction works at the SOH. Impacts to internal sensitive spaces within the SOH will be managed via administrative controls by scheduling of noise-generating activities outside of the operational hours of the SOH venues.

For external receivers, the NSW *Interim Construction Noise Guideline* (ICNG) provides recommended noise levels for airborne construction noise at sensitive land uses for State-controlled projects in NSW. The guideline provides construction management noise levels above which all feasible and reasonable work practices should be applied to minimise the construction noise impact. The ICNG works on the principle of a "screening" criterion – if predicted or measured construction noise exceeds the ICNG levels then the construction activity must implement all "feasible and reasonable" work practices to reduce noise levels. As such, the noise targets set by the ICNG are "management levels" for noise rather than strict "noise limits".

The ICNG sets out management levels for noise at noise sensitive receivers, and how they are to be applied. These management noise levels for residential receivers are reproduced below, in Table 4. Noise levels apply at the worst affected property boundary of the residence, at a height of 1.5 m above ground level. If the property boundary is more than 30 m from the residences, the noise levels apply at the most noise-affected point within 30 m of the residence.

Table 4: ICNG management levels for airborne construction noise at residences

Time of day	**Management Level, $L_{Aeq,15min}$**	**How to apply**
Recommended standard hours: Monday to Friday 7 am to 6 pm Saturday 8 am to 1 pm No work on Sundays or Public Holidays	Noise affected RBL + 10 dB	The noise affected level represents the point above which there may be some community reaction to noise. Where the predicted or measured LAeq (15 min) is greater than the noise affected level, the proponent should apply all feasible and reasonable work practices to meet the noise affected level. The proponent should also inform all potentially impacted residents of the nature of works to be carried out, the expected noise levels and duration, as well as contact details.
	Highly noise affected 75 dB(A)	The highly noise affected level represents the point above which there may be strong community reaction to noise. Where noise is above this level, the relevant authority (consent, determining or regulatory) may require respite periods by restricting the hours that the very noisy activities can occur, taking into account: Times identified by the community when they are less sensitive to noise (such as before and after school for works near schools, or mid-morning or mid-afternoon for works near residences). If the community is prepared to accept a longer period of construction in exchange for restrictions on construction times.

Time of day	Management Level, $L_{Aeq,15min}$	How to apply
Outside recommended standard hours	Noise affected RBL + 5 dB	A strong justification would typically be required for works outside the recommended standard hours. The proponent should apply all feasible and reasonable work practices to meet the noise affected level. Where all feasible and reasonable practices have been applied and noise is more than 5 dB(A) above the noise affected level, the proponent should negotiate with the community.

For work within standard construction hours, if after implementing all "feasible and reasonable" work practices to reduce noise levels the site still exceeds the Noise Affected Level, the ICNG does not require any further action – since there is no further engineering scope for noise mitigation.

For out-of-hours work, the ICNG uses a level 5 dB above the noise-affected level as a threshold where the proponent should negotiate with the community.

Table 5: ICNG screening criteria for SOH Construction Works, dB re 20µPa

Receiver	Time Period	Noise Affected Level, $L_{Aeq,15min}$	Highly Noise Affected Level, $L_{Aeq,15min}$
Bennelong Apartments	Day (standard hours)	68 dB	75 dB
	Day (outside hours)	63 dB	-
	Evening	62 dB	-
	Night	53 dB	-

5.2.1 Sleep disturbance

Noise emanating from construction works in the Lower Concourse has been assessed for its potential to disturb sleep. The NSW EPA has made the following policy statement with respect to sleep disturbance:

> *Peak noise level events, such as reversing beepers, noise from heavy items being dropped or other high noise level events, have the potential to cause sleep disturbance. The potential for high noise level events at night and effects on sleep should be addressed in noise assessments for both the construction and operational phases of a development. The INP does not specifically address sleep disturbance from high noise level events.*
>
> *Research on sleep disturbance is reviewed in the* NSW Road Noise Policy*. This review concluded that the range of results is sufficiently diverse that it was not reasonable to issue new noise criteria for sleep disturbance.*
>
> *From the research, the EPA recognised that the current sleep disturbance criterion of an $L_{A1, (1\ minute)}$ not exceeding the $L_{A90, (15\ minute)}$ by more than*

15 dB(A) is not ideal. Nevertheless, as there is insufficient evidence to determine what should replace it, the EPA will continue to use it as a guide to identify the likelihood of sleep disturbance. This means that where the criterion is met, sleep disturbance is not likely, but where it is not met, a more detailed analysis is required.

The detailed analysis should cover the maximum noise level or $L_{A1, (1\ minute)}$, that is, the extent to which the maximum noise level exceeds the background level and the number of times this happens during the night-time period. Some guidance on possible impact is contained in the review of research results in the NSW Road Noise Policy. *Other factors that may be important in assessing the extent of impacts on sleep include:*

- *how often high noise events will occur*
- *time of day (normally between 10pm and 7am)*
- *whether there are times of day when there is a clear change in the noise environment (such as during early morning shoulder periods).*

The $L_{A1, (1\ minute)}$ descriptor is meant to represent a maximum noise level measured under 'fast' time response. The EPA will accept analysis based on either $L_{A1, (1\ minute)}$ or $L_{A, (Max)}$.
Source: http://www.epa.nsw.gov.au/your-environment/noise/industrial-noise/nsw-industrial-noise-policy/applying-industrial-noise-policy

In summary, the sleep disturbance criteria of $L_{A1(1min)} \leqslant L_{A90(15min)} + 15dB(A)$ is to be used for initial assessment. The L_{Amax} may be used as an alternative to the $L_{A1(1min)}$. It is noted that the background $L_{A90(15minute)}$ noise level used for establishing the sleep disturbance criteria includes all background noise including noise from the project prior to construction (ie the noise measurements used to derive the L_{A90} were conducted with the Opera House in normal operation).

The sleep disturbance criteria for the project are presented in Table 6.

Table 6: Sleep disturbance criteria

Receiver	**Sleep disturbance criteria, 10pm - 7am, dB$L_{A1,1min}$**
	dB$L_{A90,15min}$ + 15
Bennelong Apartments	63 dB

6 Operational Noise

The Lower Concourse is one of Sydney's favourite gathering places, providing an open, causal place for people to meet, eat, drink, learn about the Opera House's heritage, book a tour or buy a souvenir. The food and beverage venues are primarily used for daytime and night-time use as a bar and catering service premise.

Live entertainment in the form of amplified music (usually consisting of two or three musicians, including a singer) is permitted at the Opera Bar until 10pm.

Currently, musicians perform live on a small stage with a vertical barrier at the southern end of the Opera Bar. However, as the barrier is considered unsightly and non-compliant with Opera House heritage policies, the proposal seeks to remove this barrier. Accordingly, this acoustic assessment predicts worse-case noise impacts with the barrier removed.

Only recorded music is provided at the Opera Kitchen. The Opera Kitchen uses a PA system to direct recorded music towards patrons.

Additionally, the Liquor Act has monitoring and enforcement provisions to regulate alcohol service and consumption, neighbourhood disturbance, alcohol-related crime and anti-social behaviour and poorly managed licensed premises, which in turn helps reduce patron noise impacts on noise sensitive receivers. The Liquor Act sets out a framework for the making and consideration of disturbance and disciplinary complaints, and allows for the imposition of conditions on licences, monetary penalties and the suspension or cancellation of a licence.

Prediction calculations have been done to check on potential noise breakout through the area of the Lower Concourse at the nearest noise sensitive residential receivers identified in Section 4.2.

6.1 Operating Hours

The reported operating hours of the Lower Concourse uses are:

- Licenced food and beverage venues:

  Sunday to Thursday – 7:30am to 12:00am

  Friday and Saturday – 7:30am to 1:00am

  New Year’s Eve – 7:30am to 2:30am

- Welcome Centre:

  Monday to Sunday – 7am to 11pm

6.2 Acoustic Modelling

Noise from operation of the facility has been modelled in Odeon Software using a LiDAR scan of the area as a base for the model. Although often used for the

modelling of internal spaces, Arup have used this software successfully for noise prediction externally, by making the boundary surfaces fully absorptive (non-sound reflective).

The reason for using this software is that it can model complex geometries and multiple reflections (as will occur from the new sun shades and the overhang of the upper deck), and also model sound distribution from commercial loudspeaker systems.

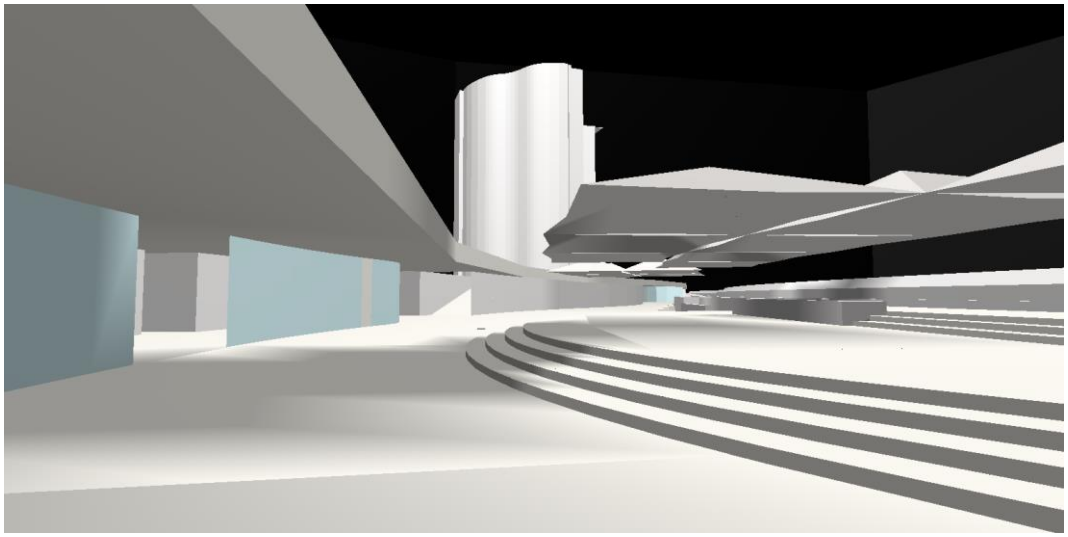


Figure 2: Acoustic model view from the Lower Concourse towards the Bennelong apartments

As can be seen above the acoustic model incorporates the new shade structures proposed over the tables. Also included in the model were four small directional loudspeakers per shade structure which will be used to play music. The sound power level of the loudspeakers is given in Table 9.

Each table in the model also includes a point source with a sound power equivalent to 10 people (see Table 7). These have been distributed along the lower concourse to match the patron numbers provided (Table 8)

The geometry of the new shades has come from the Revit model and has been imported into the model.

Noise levels within the Bennelong Apartments have been assessed on the basis of a nominal room of 100m^3 with approximately 15m^2 of external façade.

6.3 Sound Sources Noise Levels

6.3.1 Patron Noise

Noise emission from groups of people is variable and difficult to predict, particularly for informal settings such as outdoor events. As an indicative

calculation for noise emission from a group of people, the Hayne et al[6] methodology has been used. The empirical methodology is based on a large number of measurements of patron noise at bars and restaurants and has been shown to be reasonably accurate. The equation linking the source level of a crowd based on the number of people is as follows:

L_w (L_{Aeq}) = 15 log N + 64, where N is the number of patrons

L_w (L_{A10}) = 15 log N + 67, where N is the number of patrons

For modelling purposes, randomly distributed smaller gatherings of up to 10 people were assessed, resulting in a sound power level of 82 dB L_{Aeq} per group. For noise modelling purposes, these groups were then distributed at various locations.

Table 7: Noise spectrum of a single group of 10 people

Source	**Level Descriptor**	**Sound Power Levels (dB)**									
		dB(A)	**Octave band centre frequency (Hz)**								
			31.5	**63**	**125**	**250**	**500**	**1k**	**2k**	**4k**	**8k**
Group of 10 people (raised voice)	L_{eq}	79	53	63	69	75	78	74	70	64	59
	L_{10}	82	56	66	72	78	81	77	73	67	62

Typical occupancy of the licenced venues in the lower concourse throughout the year is presented in Table 8.

Table 8: Expected occupancy for venues in the lower concourse

Venue	**Season**	**Period**	**Typical maximum number of patrons**
Opera bar	Summer	Afternoon	800
		Evening	1600
	Winter	Afternoon	200
		Evening	800
Opera kitchen	Summer	Afternoon	500
		Evening	750
	Winter	Afternoon	280
		Evening	550

Figure 3 shows the location of the noise sources used for prediction within the Lower Concourse model. The summer occupancy figures are higher and have been used for the assessment.

[6] Hayne, Taylor, Rumble and Mee (2011) *Prediction of Noise from Small to Medium Sized Crowds*, Proceedings of Acoustics 2011, Gold Coast

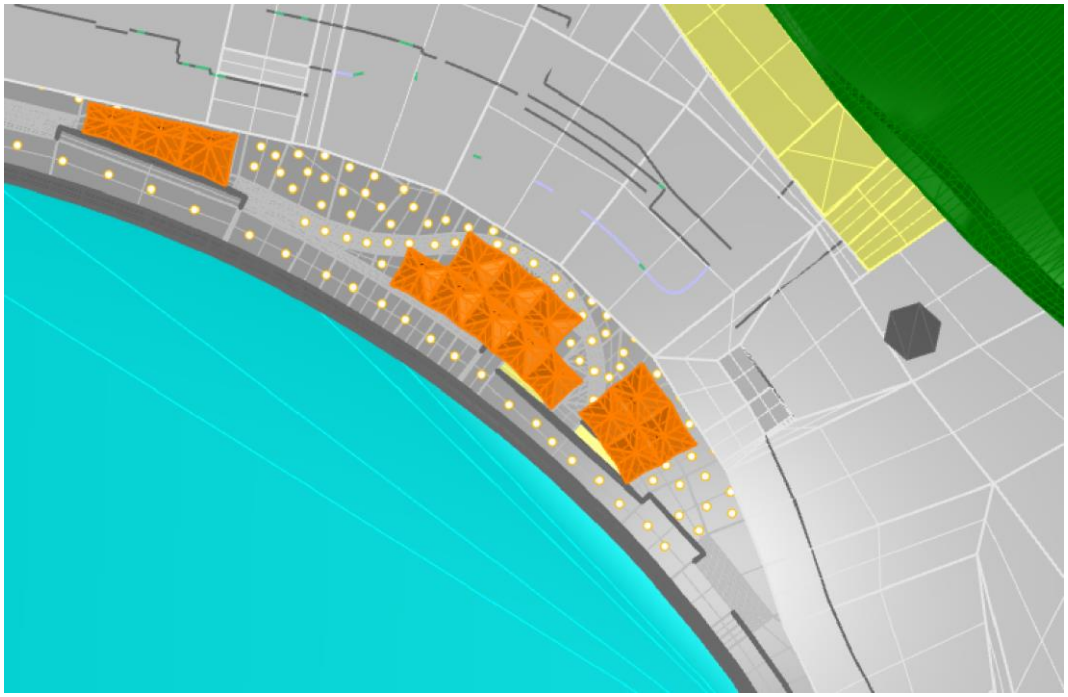


Figure 3: Site plan of the lower concourse showing locations of noise sources during normal hours of operation on a summer evening. Yellow dots indicate a sound source of 10 people. The canopies have 10 people plus loudspeakers.

6.3.2 PA System

An indicative layout of the PA system to be used across the Lower Concourse is shown in Figure 3. Expected uses of the PA system include:

- Amplified speech for announcements
- Amplified music during hours of operation

Opera Bar uses the PA system for both recorded and live amplified music, where the Opera Kitchen only uses it to play recorded music.

The upgrade of the shading structures will include an upgrade of the sound system which will include four loudspeakers per shading structure. Locating loudspeakers close to people is a well-documented means to reduce noise spillage from venues as good and even coverage of sound can be achieved at relatively low loudspeaker settings.

A typical loudspeaker frequency spectrum shape (with low-frequency allowance) has been assumed to represent a worst-case use with foreground music (refer to Table 9). The sound level was modelled to a maximum sound pressure level of 80 dB L_{Aeq} at normal hearing height per table when playing live music and 70 dB L_{Aeq} when playing back recorded background music. The sound power for each loudspeaker is presented in Table 9, which has been calculated from a typical small column loudspeaker type, taking account of the loudspeaker polar sound radiation pattern.

Table 9: Noise spectrum of each loudspeaker for the PA system

Source	Level Descriptor	Sound Power Levels (dB)								
		dB(A)	Octave band centre frequency (Hz)							
			31.5	63	125	250	500	1k	2k	4k	8k
Live music	L_{eq}	81	-	71	79	78	77	76	73	71	72
	L_{10}	86	-	76	84	83	82	81	78	76	77
Background music	L_{eq}	71	-	61	69	68	67	66	63	61	62
	L_{10}	76	-	66	74	73	72	71	68	66	67

It is noted that currently at the Opera Bar, live music is permitted outdoors however, it must cease by 10pm and respect the décor and ambience of the venue (and the limits in the Liquor licence); at the Opera Kitchen no live music is permitted and recorded music must be at an acceptable level according to SOHT guidelines.

6.4 Predicted Noise Levels at Receiver

It was noted that the predicted noise levels were higher for the upper floors at the Bennelong Apartments as these receivers would have less benefit from shielding of the upper concourse.

It is assumed that the façade glazing at the Bennelong Apartments consists of 10 mm single glazing panels for windows and balcony doors.

The following assumptions were considered for the acoustic model to predict the noise levels at the nearest noise sensitive receiver:

6.4.1 Daytime opening hours

- Number of patrons: 1300, during summer afternoon (12:00pm – 6:00pm)
- Outdoor area in use at Opera Bar, Opera Kitchen and Welcome Centre
- PA system for announcements and live music

Table 10: Predicted noise levels at the nearest noise sensitive receiver and assessed against project relevant noise criteria

Receiver	Level Descriptor	Sound Pressure Levels, dBL_{A10}								
		Octave band centre frequency (Hz)								
		31.5	63	125	250	500	1k	2k	4k	8k
Bennelong apartments	Predicted daytime noise level (external)	-	50	58	59	60	57	52	48	41
	Predicted daytime noise level (internal)	-	31	34	32	27	23	17	5	-3
	Project specific day criteria (internal)	58	47	41	36	35	30	23	17	17
	Criteria exceedance	-	-	-	-	-	-	-	-	-

6.4.2 Evening opening hours

- Number of patrons: 2350, during summer evening (6:00pm – 10:00pm)
- Outdoor area in use at Opera Bar, Opera Kitchen
- PA system for announcements and live music

Table 11: Predicted noise levels at the nearest noise sensitive receiver and assessed against project relevant noise criteria

Receiver	Level Descriptor	Sound Pressure Levels, dBL_{A10}								
		Octave band centre frequency (Hz)								
		31.5	63	125	250	500	1k	2k	4k	8k
Bennelong apartments	Predicted evening noise level (external)	-	51	59	60	61	58	54	48	41
	Predicted evening noise level (internal)	-	32	34	33	29	24	18	5	-3
	Project specific evening criteria (internal)	58	47	41	36	35	30	23	17	17
	Criteria exceedance	-	-	-	-	-	-	-	-	-

6.4.3 Night-time opening hours

- Number of patrons: 2350, during summer night (10:00pm – 12:00am)
- Outdoor area in use at Opera Bar, Opera Kitchen
- PA system for announcements and background music

Table 12: Predicted noise levels at the nearest noise sensitive receiver and assessed against project relevant noise criteria

Receiver	Level Descriptor	Sound Pressure Levels, dBL_{A10}								
		Octave band centre frequency (Hz)								
		31.5	63	125	250	500	1k	2k	4k	8k
Bennelong apartments	Predicted night noise level (external)	-	46	52	57	60	56	51	43	33
	Predicted night noise level (internal)	-	27	28	31	27	22	16	0	-11
	Project specific night criteria (internal)	58	47	41	36	35	30	23	17	17
	Criteria exceedance	-	-	-	-	-	-	-	-	-

6.5 Discussion of Operational Noise Level Results

The noise model results are consistent with the current activities and noise levels measured from normal uses in the lower concourse. The analysis shows that it is not expected that the new glazing line nor the new shading structures will significantly impact the noise emissions from patrons or music.

The predicted noise levels inside the Bennelong apartments are predicted to comply with the internal noise criteria. This is consistent with measurements undertaken by others (see footnote 3) that have shown that activity at the Opera Bar complies with the requirements of the respective licensing requirements.

The predicted results were calculated *without* the small barrier behind the current live performance stage in front of the opera bar and with the new shading structures in place. It is noted that these elements provide only a small reduction in the noise levels predicted at the noise sensitive receivers (the difference in noise levels with and without these elements was less than 1 dB). This is because much of the total overall sound power from the concourse comes from speech rather than music and that many of the tables will remain unshaded.

As can be seen, the resulting noise levels do not exceed the internal noise criteria for Bennelong Apartments, considering outdoors use of the sound system for live music must cease by 10pm. This is an expected conclusion given that there is no material change to the external activity and that the architectural changes would only serve to reduce noise (albeit by a small amount).

7 Construction Noise

7.1 Assumptions

Indicative construction activity noise source levels have been assumed for the construction works, based on previous construction noise assessments for building projects conducted by Arup and detailed discussions with construction specialists on the likely construction methodology for the project.

Construction noise impacts are expected to be minor. The highest noise impact activities include:

- Cutting in a new doorway, involving
  - Core holes drilling in the top corners and potentially down the sides of the opening to prevent over cuts
  - concrete sawing the opening out in manageable sections
- Realigning the existing glazing, involving
  - Cordless tools, drill, grinders and the like will be used
  - Potentially percussion drills to fix in any new ground anchors
- Installing new shade sails, including
  - In-situ coring new sail locations on the existing calca panels
  - Transporting calca panels into location (using equipment regularly used for maintenance).
  - Fixing base of the shade sail in place with chemical anchors drilled with percussion drills

The sound power levels for typical construction equipment for each phase of works are given in Table 13, accounting for the likely usage patterns of items of equipment over a typical 15-minute period (which is the assessment time frame for construction noise levels under the ICNG).

It is worth noting that many of the deliveries/removals are expected to make use of the underground route and so will not disturb the nearest residential receivers from the noise of loading and unloading activities. A maximum of two trucks per night is expected. Trucks will not queue externally.

The site facilities will mostly be located on the lower concourse, screened by the upper concourse. The facilities are thus screened from the nearest residential locations.

7.2 Working Hours

The majority of site work will be undertaken during normal site working hours (7am to 6pm Monday to Friday and 8am to 1pm on Saturday). There will be no work on Sundays or Public Holidays.

The work is not expected to impact on operation of the SOH.

7.3 Source Noise Levels

Sound levels for items of construction plant have been obtained from the databases in BS5228.1[7] and AS2436[8].

Items of plant that have particularly-annoying characteristics (e.g. impulsive or tonal noise characteristics, such as cutting or drilling equipment) have had a +5 dB adjustment penalty applied to account for these characteristics, as required by the ICNG.

For on-site deliveries, equivalent line-source sound power levels have been calculated based on the published maximum pass-by levels for haul trucks from BS 5228.1.

Table 13 summarises the construction source levels and the major items of construction equipment modelled for each major construction activity:

Table 13: Construction Activities, Lower Concourse Works

Activity	**Construction Equipment**	**Activity Sound Power Level, dB re 1pW**
External works	Mostly hand tools to remove façade elements and occasional mobile crane and forklifts / bobcats	$L_{eq,adj,15min}$ 99 dB(A)
External fitout works	Drilling, 5 hand-held hammer drills	$L_{eq,adj,15min}$ 116 dB(A) (includes 5 dB tonal penalty)
Deliveries/removal	Haul truck/trailer	$L_{eq,adj,15min}$ 71 dB(A)

7.4 Predicted Noise Levels

Construction noise levels for external fitout works have been predicted for the sources given in Table 13 using the acoustic modelling software described in Section 6.2. The noisiest conditions are expected during this stage of works and therefore the noise levels represent a predicted worst-case scenario of 5 hand-held drills *being used simultaneously* for the entire 15-minute assessment period.

[7] British Standard BS5228-1: 2009 + A1 :2014 *Code of practice for noise and vibration control on construction and open sites – Part 1: Noise*
[8] Australian Standard AS2436 (2010) *Guide to noise and vibration control on construction, demolition and maintenance sites*

Indicative noise source locations were assumed as follows:

Lower concourse – 3 scenarios

1. All 5 drills in use at the current location of the Opera Bar, along the external face of the glazing. No hoarding in place.
2. All 5 drills in use at the current location of the Opera Bar, along the external face of the glazing. Hoarding in place enclosing the lower concourse area below the upper concourse.
3. 2 drills in use beside the Opera Bar umbrellas nearest to Bennelong Apartments and 3 drills in use along the external face of the Opera Bar glazing. No hoarding in place

The estimated distance between the SOH Lower Concourse construction works and noise sensitive receivers being of the order of 70 m, the actual source location chosen has minimal influence on the results, and hence activities in similar areas can be modelled as a single source location with minimal error. Allowance for acoustic screening by the Upper Concourse itself has been made where appropriate, although the effect is minimal.

Site plans showing the indicative construction source locations are presented in Figure 4 and Figure 5.

Figure 4: Indicative construction source locations – scenario 1 (yellow dots indicate source location)

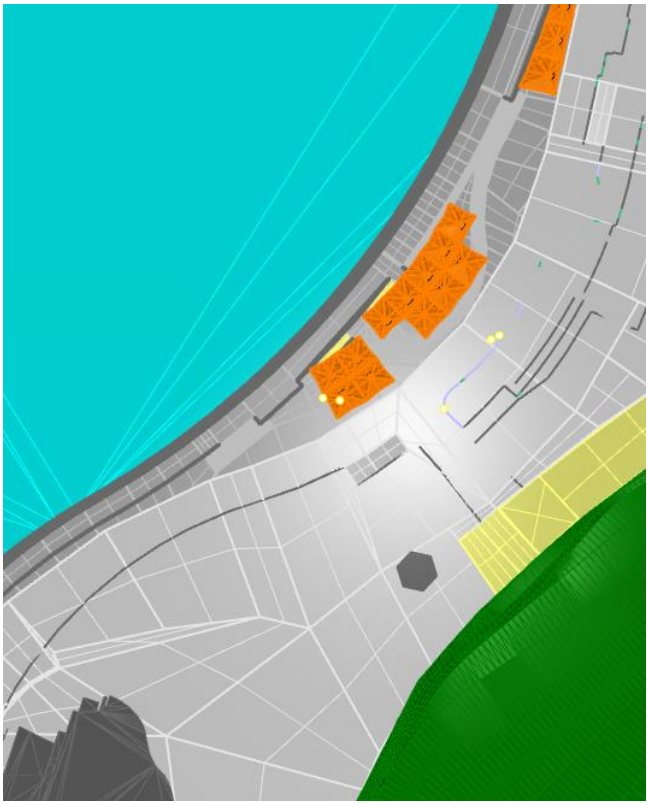


Figure 5: Indicative construction source locations - scenario 3 (yellow dots indicate source location)

Table 14 presents a summary showing the highest predicted noise level at the most noise-sensitive receiver catchment (Bennelong Apartments) and presents the ICNG construction screening criteria for comparison.

Table 14: Construction Noise Screening Calculations for External Fitout Works, Sydney Opera House, Lower Concourse, dB re 20 µPa

Source Location	**Receiver Location**	**Scenario**	**Predicted Construction Noise Level, $dBL_{Aeq,adj,15min}$**	**Noise Affected Level, dB(A)**			
				Day (Standard Hrs)	**Day (Outside Hrs)**	**Evening**	**Night**
Lower Concourse	Bennelong Apartments	1	71	68	63	62	53
		2	44				
		3	73				

The predicted noise levels for work scenarios 1 and 3 slightly exceed the noise affected level for standard working hours. As the predicted noise levels represent a worst-case scenario (5 drills operating simultaneously and continuously for a full 15 minutes), it is expected that most external works undertaken with no hoarding are likely to comply with the daytime noise affected levels during standard working hours.

Scenario 2 was developed using scenario 1 as basis and including full height (i.e. floor to ceiling) hoarding below the upper concourse with a lightweight construction such as MDF boards. This scenario is considered for out-of-hours works in areas that can be enclosed by the hoarding line described (e.g. glass realignment works). The predicted noise level assessed for a worst-case scenario (5 drills operating simultaneously and continuously for a full 15 minutes) are not expected to exceed the criteria during out-of-hours daytime, evening or night-time works.

Notwithstanding this, proposals are made below (section 7.5) to limit noise levels as far as is reasonably practicable.

7.4.1 Sleep Disturbance - Maximum Noise Levels

As stated previously:

- The work at night would only take place internally or inside areas enclosed with full height acoustic hoarding described in previous sections and would be restricted to operations which would otherwise be disruptive to Opera House operations.
- Many of the deliveries/removals are expected to make use of the underground route and so will not disturb the nearest residential receivers from the noise of loading and unloading activities. A maximum of two trucks per night is expected. Trucks will not queue externally.

Therefore, noise due to construction activities at night is expected to be minimal; night-time $L_{A1(1min)}$ noise levels predicted to be well below the sleep disturbance criteria of 63 dB(A).

7.5 Noise Mitigation

The following noise mitigation work practices are recommended to be adopted at all times on site:

- Regularly train workers and contractors (such as at toolbox talks) to use equipment in ways to minimise noise
- Ensure site managers periodically check the site and nearby residences for noise problems so that solutions can be quickly applied
- Prohibit the use of radios or stereos
- Avoid the overuse of public address systems
- Avoid shouting, and minimise talking loudly and slamming vehicle doors
- Use non - “beeper” reversing/movement alarms such as broadband (non-tonal) alarms or ambient noise-sensing alarms
- Turn off all vehicles, plant and equipment when not in use
- Use residential-grade mufflers on plant
- Ensure all doors/hatches are shut

- Ensure that vehicles do not arrive outside the site or wait in nearby residential areas outside the approved construction hours
- Conduct work behind temporary hoardings/screens wherever possible. Site hoardings should be located as close to the noise source as possible and should be as high as feasible considering the structural support of the hoarding. Site hoardings may not be effective at screening noise to upper floors of sensitive receivers but can be an effective noise mitigation measure for receivers located on lower floors.

8 Recommendations

On the basis of the above analysis, it is concluded that the proposed upgrades to the lower concourse described in this document would not have a detrimental impact on the nearest noise sensitive receivers. However, to minimise potential for noise nuisance, the following recommendations are made.

8.1 Construction Noise

The SOH has recognised noise issues affecting nearby neighbours during external construction works in the past. Therefore, the Sydney Opera House intends that contractors who are undertaking noisy external works identify mitigation measures for this work in their CNMP which they will be required to prepare before work starts on site. This CNMP will be reviewed by the SOH and their noise consultants prior to approval and implementation on site.

The Contract with the Managing Contractor will include a clause allowing SOH to disallow any equipment that it considers to be excessively noisy. Similarly, the Managing Contractor may include incentives, as it sees fit, for sub-contractors who can provide noise mitigation measures as part of their contract works.

Should complaints be received, attended acoustic monitoring will be undertaken to ascertain the 'noisier' work activities and address specific work practices and locations to better alleviate noise complaints from that particular activity. A noise logger will also be installed if complaints are received.

Following identification that all noise levels have returned to being consistently below the above maximum levels the monitoring will revert to remote monitoring.

To summarise:

- The recommendations regarding noise mitigation given in Section 7.5 above be implemented.
- Limiting external works at night to only those that are required because they cannot be accommodated at other times.
- The eventual Contractor be required to prepare a Construction Noise Management Plan.

8.2 Operational Noise

A detailed acoustic model has been created to allow the calculation of noise levels from the operation of the lower concourse. Modelling of noise from patron noise and from background and foreground music has shown that noise can be kept to acceptable levels provided the current controls on operational hours are maintained.

It is worth noting that the proposals for the Lower Concourse do not fundamentally change its current use. The new shade structures are intended to be constructed of a heavier material than the existing and as such would be marginally better at controlling noise spread from sounds generated below them.

Also, the new loudspeakers installed as part of the upgrade will be carefully aligned to optimise the sound distribution over the patrons.

Appendix A

Environmental Noise Surveys

A1.1 Environmental Noise Survey

The noise environment is typical of a busy harbour and inner city. The major noise sources consist of nearby road vehicle traffic and railway noise (i.e. Harbour Bridge) as well as helicopter and ferry noise in Sydney Harbour.

As required by NSW Industrial Noise Policy, an ambient noise survey was conducted in the area from Wednesday, 13 July 2016 to Thursday, 21 July 2016 to determine the existing ambient noise levels at the nearest residential receivers. Additional data was obtained from previous surveys conducted by Arup and Auditoria.

Unattended (noise logging) and attended measurements were conducted to determine representative ambient noise levels in the vicinity of the site during the relevant hours of operation.

A1.2 Methodology

Long term noise monitoring equipment was set up at four locations to log 15-minute measurement intervals of L_{Aeq}, L_{A10} and L_{A90} with a fast (0.125s) time weighting.

Meteorological conditions were monitored during the survey period. The relevant measurement intervals affected by adverse weather and extraneous noise events were removed.

Short term 15-minute attended measurements were undertaken at ground level in front of the Bennelong apartments on 13 May and 14 May, 2019 to obtain detailed noise information for daytime, evening and night-time noise environment near the receiver.

A1.3 Measurement Locations

Figure 1 shows the four noise logger locations on a map of the area. Logger locations were chosen taking into account security and access restrictions and are considered representative of the surrounding areas and nearest potentially affected receivers.

Unattended noise monitoring data was provided by Auditoria for locations 1 and 2. Loggers were positioned on level 4 and level 9 at the northern façade of Bennelong Apartments as shown in figure 2 (left).

Figure 1: Map of logger locations.

Figure 2: Noise monitoring location at Bennelong Apartments (left)

A1.4 Equipment

The equipment used to measure the baseline noise levels is detailed in Table 1.

Table 1: Equipment used to conduct noise survey

Type	Model	Serial No.	Location
Noise Logger	ARL Ngara Type 1 Microphone	8780b4	Bennelong level 4
Noise Logger	ARL Ngara Type 1 Microphone	8780f0	Bennelong level 9
Sound Level Meter	Brüel & Kjaer Type 2270	2754328	
Sound Level Meter	Brüel & Kjaer Type 2250	2449851	
Calibrator	Brüel & Kjaer Type 4231	3000079	

A1.5 Short Term Attended Noise Measurement Results

Short term measurements (15-minutes) of environmental noise were carried out at ground floor in front of Bennelong apartments. The attended measurement results a summarized in Table 2.

Table 2: Attended noise survey results

Receiver	Date and Time	Rating	Sound Pressure Level, dB re 20µPa									
			dB(A)	Octave Band Centre Frequency, Hz[1]								
				31.5	63	125	250	500	1k	2k	4k	8k
Ground floor near Bennelong Apartments	14 May 2019 09:51:57	L_{eq}	65	73	71	69	65	61	60	57	53	46
		L_{90}	60	67	65	63	59	56	55	53	49	43
	13 May 2019 20:22:24	L_{eq}	60	72	70	63	57	55	54	53	50	45
		L_{90}	58	63	64	58	54	52	52	51	48	44
	13 May 2019 22:11:23	L_{eq}	55	75	66	58	54	53	50	46	41	35
		L_{90}	52	62	59	55	51	49	47	41	33	26

A1.6 Long Term Unattended Noise Logging Results

Measured noise levels from the unattended noise survey at all four locations is summarised in Table 3. Summary results have been split into standard Day, Evening and Night time periods as defined in the NSW Industrial Noise Policy.

Averaged daily summary graphs of the noise logging are provided in Section A1.7 and individual daily graphs are available upon request.

Table 3: Summary of measure noise indices

Location	Time Period	Rating Background Level (RBL) – dB(A)	$L_{Aeq\ (period)}$, dB
Location 1 - Level 4, 1e Macquarie Street	Day (7:00 – 18:00)	59	64
	Evening (18:00 – 22:00)	59	62
	Night (22:00 – 7:00)	48	57
Location 2 - Level 9, 1e Macquarie Street	Day (7:00 – 18:00)	58	62
	Evening (18:00 – 22:00)	57	61
	Night (22:00 – 7:00)	49	56
Combined Bennelong data for report*	Day (7:00 – 18:00)	58	62
	Evening (18:00 – 22:00)	57	61
	Night (22:00 – 7:00)	48	56

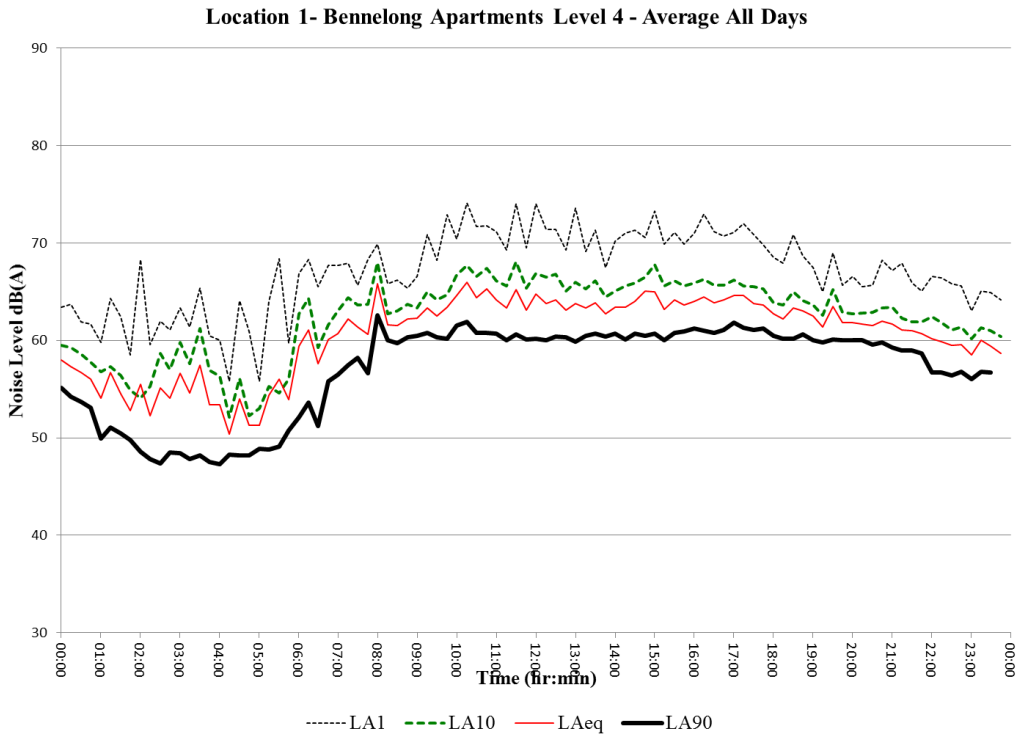
Note: The background noise levels from two monitoring locations at Bennelong Apartments were combined for simplicity in the report (Section 4.1 - Table 1). The lowest values were taken for the most stringent criteria.

A1.7 Observations

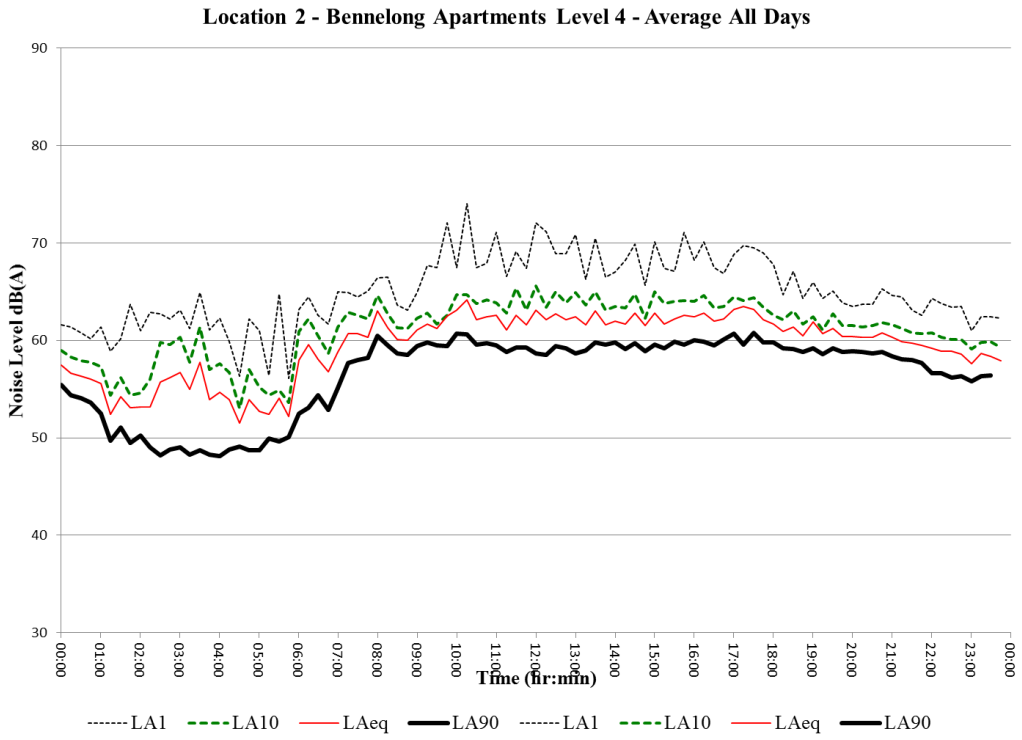
Ambient noise levels are generally constant between the hours of 8:00 am and 9:00 pm for the receivers located at the Bennelong apartments.

A1.8 Survey Data

A1.8.1 Location 1 – Bennelong Apartments level 4



A1.8.2 Location 2 - Bennelong Apartments Level 9



Appendix B

Acoustic Glossary

Ambient Noise Level

The ambient noise level is the overall noise level measured at a location from multiple noise sources. When assessing noise from a particular development, the ambient noise level is defined as the remaining noise level in the absence of the specific noise source being investigated. For example, if a fan located on a city building is being investigated, the ambient noise level is the noise level from all other sources without the fan running. This would include sources such as traffic, birds, people talking and other nearby fans on other buildings.

Background Noise Level

The background noise level is the noise level that is generally present at a location at all or most times. Although the background noise may change over the course of a day, over shorter time periods (e.g. 15 minutes) the background noise is almost-constant. Examples of background noise sources include steady traffic (e.g. motorways or arterial roads), constant mechanical or electrical plant and some natural noise sources such as wind, foliage, water and insects.

Assessment Background Level (ABL)

A single-number figure used to characterise the background noise levels from a single day of a noise survey. ABL is derived from the measured noise levels for the day, evening or night time period of a single day of background measurements. The ABL is calculated to be the tenth percentile of the background L_{A90} noise levels – i.e. the measured background noise is above the ABL 90% of the time.

Rating Background Level (RBL)

A single-number figure used to characterise the background noise levels from a complete noise survey. The RBL for a day, evening or night time period for the overall survey is calculated from the individual Assessment Background Levels (ABL) for each day of the measurement period, and is numerically equal to the median (middle value) of the ABL values for the days in the noise survey.

Decibel

The decibel scale is a logarithmic scale which is used to measure sound and vibration levels. Human hearing is not linear and involves hearing over a large range of sound pressure levels, which would be unwieldy if presented on a linear scale. Therefore a logarithmic scale, the decibel (dB) scale, is used to describe sound levels (dB SPL ref 20µPa).

An increase of approximately 10 dB corresponds to a subjective doubling of the loudness of a noise. The minimum increase or decrease in noise level that can be noticed is typically 2 to 3 dB.

dB(A)

dB(A) denotes a single-number sound pressure level that includes a frequency weighting ("A-weighting") to reflect the subjective loudness of the sound level.

The frequency of a sound affects its perceived loudness. Human hearing is less sensitive at low and very high frequencies, and so the A-weighting is used to account for this effect. An A-weighted decibel level is written as dB(A).

Some typical dB(A) levels are shown below.

Noise Level dB(A)	Example
130	Human threshold of pain
120	Jet aircraft take-off at 100 m
110	Chain saw at 1 m
100	Inside nightclub
90	Heavy trucks at 5 m
80	Kerbside of busy street
70	Loud stereo in living room
60	Office or restaurant with people present
50	Domestic fan heater at 1m
40	Living room (without TV, stereo, etc)
30	Background noise in a theatre
20	Remote rural area on still night
10	Acoustic laboratory test chamber
0	Threshold of hearing

L_{10}

The L_{10} statistical level is often used as the "average maximum" level of a sound level that varies with time.

Mathematically, the L_{10} level is the sound level exceeded for 10% of the measurement duration. L_{10} is often used for road traffic noise assessment. As an example, 63 dB $L_{A10,18hr}$ is a sound level of 63 dB(A) or higher for 10% of the 18 hour measurement period.

L_{90}

The L_{90} statistical level is often used as the "average minimum" or "background" level of a sound level that varies with time.

Mathematically, L_{90} is the sound level exceeded for 90% of the measurement duration. As an example, 45 dB $L_{A90,15min}$ is a sound level of 45 dB(A) or higher for 90% of the 15 minute measurement period.

L_{eq}

The 'equivalent continuous sound level', L_{eq}, is used to describe the level of a time-varying sound or vibration measurement.

L_{eq} is often used as the "average" level for a measurement where the level is fluctuating over time. Mathematically, it is the energy-average level over a period of time (i.e. the constant sound level that contains the same sound energy as the measured level). When the dB(A) weighting is applied, the level is denoted dB L_{Aeq}. Often the measurement duration is quoted, thus $L_{Aeq,15\ min}$ represents the dB(A) weighted energy-average level of a 15 minute measurement.

L_{max}

The L_{max} statistical level can be used to describe the "absolute maximum" level of a sound or vibration level that varies with time.

Mathematically, L_{max} is the highest value recorded during the measurement period. As an example, 94 dB L_{Amax} is a highest value of 94 dB(A) during the measurement period.

Since L_{max} is often caused by an instantaneous event, L_{max} levels often vary significantly between measurements.

Frequency

Frequency is the number of cycles per second of a sound or vibration wave. In musical terms, frequency is described as "pitch". Sounds towards the lower end of the human hearing frequency range are perceived as "bass" or "low-pitched" and sounds with a higher frequency are perceived as "treble" or "high pitched".

Sound Power and Sound Pressure

The sound power level (Lw) of a source is a measure of the total acoustic power radiated by a source. The sound pressure level (Lp) varies as a function of distance from a source. However, the sound power level is an intrinsic characteristic of a source (analogous to its mass), which is not affected by the environment within which the source is located.