Sound Intensity Measurements for Ranking Noise Transmission Through Building Envelope Elements

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ABSTRACT

Entertainment and community buildings frequently have to be designed to contain performance noise in order to meet acceptable noise levels at surrounding noise sensitive premises. Typically, a noise source would be generated within the building and sound pressure measurements would be conducted externally to determine the noise level radiating from various elements of the building envelope. Due to the microphone systems typically used on sound level meters, extraneous ambient noise, such as traffic noise, or noise transmission through adjacent building elements may be inadvertently included in the noise measurements. During the design of a proposed building upgrade, a study was conducted to rank noise emissions through the building elements of a local community building. As an alternative to the sound pressure level measurement method, sound intensity was utilised to focus on the noise transmission through individual building elements. These individual sound intensity measurements were conducted in a grid point array along all sides of the external façade of the building and above the roof. This allowed the construction of sound power level contour maps for use in determining a ranking of the acoustic performance of the building elements. The measurements were conducted generally in accordance with ISO9614.1-1993. This paper presents the results of the sound intensity measurements, and investigates the validity of using the sound intensity technique for noise ranking of building elements. Additionally, sound pressure measurements were conducted adjacent to the building elements, including windows, doors, walls and roof, to enable calculation of sound power levels. A comparison of the results achieved for the two methods is discussed.

INTRODUCTION

The ranking of noise emissions through building elements is often requested of acoustic consultants for various building types; which typically includes commercial, industrial and community buildings. The ranking would typically be achieved by conducting sound pressure level measurements around the building envelope whilst ensuring the sound level meter is within the near field of the building, in an attempt to reduce extraneous noise intrusion from unwanted noise sources. However, near multiple panes of glazing or building elements with reduced acoustical performance, noise emissions from the multiple building elements can be measured, which may lead to inaccurate acoustical performance results and an incorrect ranking of the noise emissions. As an alternative to sound pressure, sound intensity measurements have been proposed.

A study was conducted to determine a ranking of the acoustical performance of building elements in a local community building. Due to the large number of elements, including glazing, sliding doors, entry doors and louvres, sound intensity measurements were conducted with the purpose of determining an accurate noise ranking and constructing noise contour maps for the easy identification of weaknesses in the building envelope. This paper presents the results of the sound intensity measurements, and investigates the validity of using the sound intensity technique for noise ranking of building elements.

In parallel with the sound intensity measurements, sound pressure measurements were conducted adjacent to the building elements to enable the theoretical calculation of sound power levels. A comparison of the results achieved by the two methods is discussed.

BUILDING LAYOUT AND LOCATION

The local community hall building has been constructed with a main auditorium, a number of meeting rooms, mother's rooms, store rooms, and an entrance greeting area attached.

The auditorium contains a stage for use by religious groups, local performers, musicians or public speakers, with seating provided to the rest of the area. It contains an in-house sound system, with multiple speakers hung from the ceiling above the stage and a mixing desk at the rear of the auditorium. The speakers faced toward the audience (to the east), however as the building contained mostly hard surfaces, the reverberant field ensured noise emissions from the auditorium was uniform in all directions.

To the east of the auditorium is the entrance greeting area and enclosed meeting room and mother's room. The greeting area is separated from the main auditorium by a full height partition. The partition is not fully segregated from the auditorium as it allows two walkways either side. To the north and south of the auditorium are full height glazed façades and associated glazed sliding doors to enclose the auditorium while allowing ingress and egress as shown in Figure 1. The western external façade is separated from the auditorium by a combination of meeting rooms and store rooms. A floor plan showing the layout of the community building is shown in Figure 2.

The building is located in a residential area along a major suburban road. The ambient noise level in the area was noted to be influenced by traffic noise along the main road and local wildlife; including birds, dogs and insects.

Figure 1: Southern side of the community building

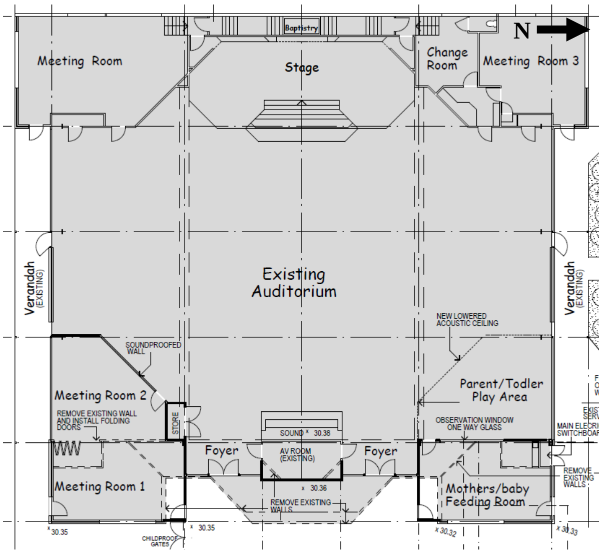

Figure 2: Floor plan for community building

METHODOLOGY

Sound Intensity Measurements

To determine the acoustical performance and noise ranking of the building elements, one-third octave sound intensity measurements were conducted around the building envelope.

Although there is no Australian Standard specifically designed for field sound intensity measurements through partitions of a building, reference was made to International Standard ISO9614-1:1993 – *Acoustics – Determination of sound power levels of noise sources using sound intensity – Part 1: Measurement at discrete points*. The grid point array method, as specified in the Standard, was selected for this study due to the size of the building and the preference to obtain noise contour maps for each façade and roof.

An alternative method is presented in ISO9614-2 which discusses the scanning method. This method is generally considered to have greater accuracy however it was considered an impractical method for the study, primarily due to the size of the source building and the requirement to walk back and forth the length of the façade during each scan. Further, movement on the roof during the scan would have produced a series of transient noises which may have invalidated the intensity measurement.

The Standard specifies that up to a maximum of 50 discreet measurement points should be selected externally for each façade and roof for large sources. Two rows of 25 points were selected for each of the four façades. The roof was segregated into a 7 x 7 point grid square with 4.5m grid spacing to create a total of 49 measurement positions. All measurements were conducted for a period of 10 seconds at a distance of 0.5m from the façades and roof as recommended in the Standard.

Pink noise was played via the mixing desk through the in-house speakers to create a continuous, broadband noise source within the auditorium. The volume of pink noise was raised until it exceeded an A-weighted noise level of 100dBA within the reverberant field of the room. A high internal noise level was required to ensure an adequate signal to noise ratio externally to the building to reduce potential error as many of the glazed partitions are full height.

Sound Pressure Measurements

Sound pressure measurements were also conducted in one-third octave bands adjacent the building elements along the external façades. Pink noise was played through the in-house speaker system at a volume greater than 100dBA in the reverberant field. However, only one sound pressure level measurement was conducted adjacent each building element rather than a grid array as with the intensity measurements.

Background sound pressure levels were also measured and determined. Where necessary, extraneous noise sources were removed from the measured sound pressure results.

Ranking

A ranking of the acoustic performance of the building elements was conducted by calculating the sound power of the measurement area and extrapolating the noise emissions to the nearest noise sensitive receivers surrounding the community building. The building and surrounding noise sensitive receivers for this study are shown in Figure 3.

Figure 3: Community building and surrounding residential noise sensitive receivers

Sound power is calculated by multiplying sound intensity by area. The power of the segregated grid areas were individually calculated using this formula and the results extrapolated to the receivers in each direction. This allowed for greater accuracy and refinement when determining the weakest performing elements.

The sound power was approximated from the single, near-field sound pressure measurements multiplied by the area of the entire partition or building element. The results were then extrapolated to the receivers in each direction.

The sound power results determined using sound pressure and sound intensity were compared to determine whether any differences were found, and to verify the noise ranking.

INSTRUMENTATION

The instrumentation used during the study included:

- SINUS Soundbook noise monitoring system type Apollo MK2-4L E (S/N: #07006);
- SINUS Type 1 intensity probe type SIS99;
- Type 1 GRAS microphone type 40AF/26AK (S/N: 62562) and gooseneck;
- Pink noise source; and
- Bruel and Kjaer type calibrator type 4231 (S/N: 2463922).

As the frequencies of interest related to music and speech noise from the community building, a spacer of 12mm was selected as part of the intensity probe. This allowed for the accurate measurement (within 1dBA) of the one-third frequency bands nominally between 125Hz and 6.3kHz as shown graphically in Figure 4, and as low as 80Hz in accordance with manufacturers specification.

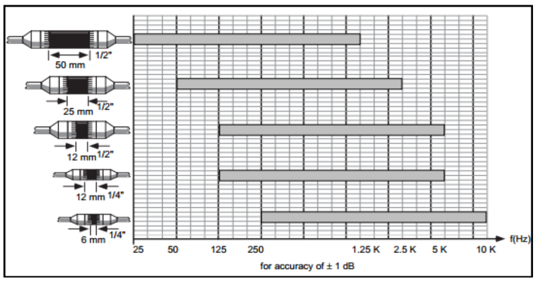

Figure 4: Typical intensity probe spacer selection (from Larson Davis Incorporated, 1999)

The computational software used in the Soundbook to analyse the sound intensity measurements and predict a sound power was the SINUS SAMURAI program. The software requires a number of variables be inserted; such as the spacer length and grid element surface area. With the variables inserted, SAMURAI instantaneously calculates the predicted sound power of the noise emitted from the nominated source area.

The probe was phase calibrated and amplitude calibrated prior to use.

SOUND INTENSITY RESULTS

The sound power results determined using sound intensity measurements are presented in Table 1.

Table 1: Sound power results from sound intensity

Roof/Walls	***Element***	**Sound Power (dBA_w)**	**Comments**
Roof	Southern Roof	97	Largely affected by rooftop louvres
	Louvres	90	Dominant noise source on roof
	Northern Roof	83	Further from speakers and louvres
East	Glass Door	73	During site measurements, noise transmission was audible through glazing and entry doors.
	Glazing	72	
	Brickwork	66	
South	Glazing	78	Full height glazing
	Brickwork	77	Brickwork very close to glazed areas.
North	Glazing	80	Full height glazing
	Brickwork	76	Brickwork very close to glazed areas.
West	Glazing	62	Low level noise emissions from western façade.
	Brickwork	60	
	Door	52	

The sound power levels were calculated via logarithmic summation to determine the results of each building element.

The emissions from the grid array of each of the elements shown in Table 1 were extrapolated to the nearest noise sensitive receivers in each direction. The noise ranking results, based on the sound power calculated from sound intensity measurements, are presented in Table 2. The ranking is presented from the poorest acoustically performing building element to the best.

Table 2: Noise ranking at receivers (intensity)

Receiver direction	***Ranking***	***Building element***	***Noise contribution (dBA)***
Eastern	1	Louvres / Roof (S)	51
	2	Glazing (N)	37
	3	Roof (N)	37
	4	Glass Door (E)	35
Southern	1	Louvres / Roof (S)	63
	2	Roof (N)	49
	3	Glazing (S)	47
	4	Glazing (S)	47
Northern	1	Louvres / Roof (S)	45
	2	Glazing (N)	41
	3	Brickwork (N)	38
	4	Glazing (N)	37
Western	1	Louvres / Roof (S)	59
	2	Glazing (N)	46
	3	Roof (N)	45
	4	Glazing (S)	44

Table 2 shows that the noise emissions in all directions were dominated by the poor acoustical performance of the southern roof section. The southern roof was predominantly affected by its proximity to the rooftop louvres, as shown in Figure 5.

Figure 5: Rooftop louvre location and southern roof

The internal ceiling sloped parallel to the external roof gradient (shown in Figure 5) so there was negligible noise reduction from the building construction. The source speakers were also located directly adjacent the louvres (within 3m) which contributed to the poor acoustic performance.

Many of the full height glazed partitions were subsequently ranked the poorest acoustically performing elements after the roof and rooftop louvres. For the northern receivers, a section of brickwork was also ranked within the worst four performing elements. The likely cause is due to its proximity to two full height glazing panes, and the potential wavefronts emitted from the glazing.

It was noted that the southern rooftop was the poorest performing element toward the north, inclusive of the attenuation provided by the partial northern roof overhang.

SOUND PRESSURE RESULTS

Acoustical theory was used to determine the sound power results based on the measured sound pressure levels. The following equation was used to obtain the sound power as the measurements were conducted within the near field:

$$SWL = \text{SPL (measured)} + 10\log(A). \qquad (1)$$

where A is the area of the building element. The results are presented in Table 3.

Table 3: Sound power results from sound pressure

Roof/Walls	*Element*	**Sound Power (dBA_w)**	**Comments**
Roof	Southern Roof	N/A	This could not be determined due to the dominance of the louvres.
	Louvres	95	Dominant noise source on roof
	Northern Roof	N/A	This could not be determined due to the dominance of the louvres.
East	Glass Door	79	During site measurements, noise transmission was audible through glazing and entry doors.
	Glazing	73	
	Brick-work	Not measured	
South	Glazing	90	Full height glazed door.
	Brick-work	N/A	Not measured.
North	Glazing	91	Full height glazed door.
	Brick-work	N/A	Not measured.
West	All	N/A	Not measured.

Table 3 shows that sound pressure measurements were not conducted at many of the intensity measurement locations. The primary reason for the incomplete data set was due to the weaker building elements (such as the louvres or glass sliding doors) producing localised dominant noise sources, leading to erroneous results when measuring adjacent the higher performing elements.

It is noted that in all cases where the sound power was approximated using the sound pressure measurements and standard acoustical theory, a higher result was produced than for the intensity measurements. Although this is an expected result, some of the differences in sound power predictions exceeded 10dBA. This is expected to be due to a number of reasons, including:

- large building element sizes (including full height glazed panes encompassing large percentages of the building façades);
- noise emissions may have been measured passing through a number of building elements;
- local building effects (such as nearby retaining walls and complex wall angles);
- the frequency range measurement restrictions when using sound intensity; and
- ambient noise levels, including traffic, birds, dogs and insects.

A noise ranking was also completed using the sound power calculations based on the sound pressure measurements. The ranking results are presented in Table 4.

Table 4: Noise ranking at receivers (pressure)

Receiver direction	*Ranking*	*Building element*	*Noise contribution (dBA)*
Eastern	1	Louvres / Roof (S)	49
	2	Glazing (N)	45
	3	Glass Door (E)	44
Southern	1	Louvres / Roof (S)	61
	2	Glazing (S)	56
	3	Glazing (S)	56
Northern	1	Glazing (N)	49
	2	Louvres / Roof (S)	48
	3	Glazing (N)	48
Western	1	Louvres / Roof (S)	57
	2	Glazing (N)	54
	3	Glazing (S)	53

As the northern roof section was unable to be measured using sound pressure, the results in Table 4 only show the top three sources for ease of comparison against the sound intensity results.

Table 4 shows that in all directions, except to the north, the rooftop louvres are the most dominant noise source.

The impact of the rooftop louvre noise at the northern receivers was found to be reduced due to the increased sound power predictions determined from the sound pressure measurements for the glazed building elements. Table 4 also shows however that the contributions from the noise transmissions through the building elements at the northern receivers are almost equivalent.

NOISE CONTOUR MAP

One of the advantages with using the discreet point sound intensity method is the ability to create post-analysis noise contour maps.

The weakest building element determined from the noise measurements was the rooftop and louvres. It was essential to create a noise contour map of the rooftop in an attempt to determine the regions of the roof that required the greatest improvement to acoustical performance.

A sound power noise contour map was created for the study based on the grid point sound intensity measurements conducted. The noise contour map was then superimposed upon an aerial photograph of the community building as shown in Figure 6.

The map clearly shows the areas of greatest concern. These areas are nearby the louvred area as expected and are particularly loud immediately adjacent the ceiling mounted speakers towards the western end of the building. These sections were highlighted as priorities for acoustical improvement.

Figure 6 shows that the northern section of the roof, which is raised above the southern section and is situated further from the speakers, emits sound power levels between 60dBA and 70dBA at each discreet location. Although of less concern that the southern side and louvres, the acoustical performance would still need to be improved, albeit at a later stage.

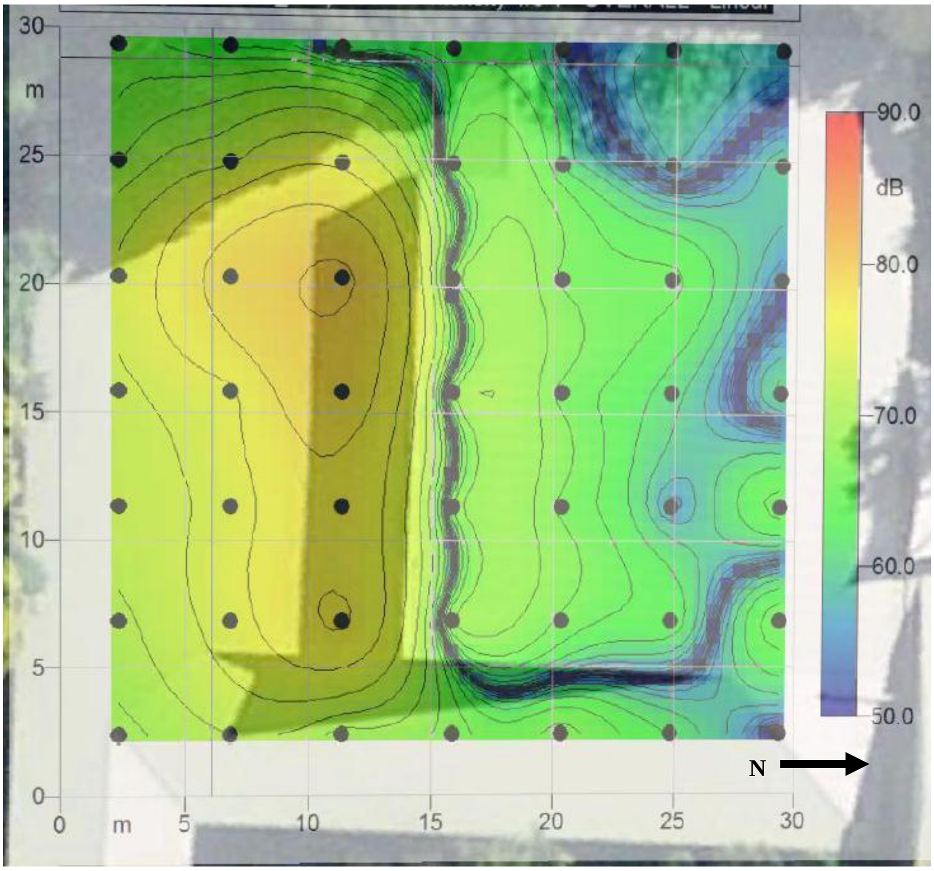

Figure 6: Rooftop sound power noise contour map

NOISE RANKING COMPARISON AND VERIFICATION

To determine the accuracy of the noise ranking conducted using the sound intensity results, a comparison of the results of the two methods is required. The ranking results are shown in Table 5.

Table 5: Noise ranking comparison

Receiver direction	*Ranking*	*Sound intensity*	*Sound pressure*
Eastern	1	Louvres/Roof (S)	Louvres/Roof (S)
	2	Glazing (N)	Glazing (N)
	3	Glass Door (E)	Glass Door (E)
Southern	1	Louvres/Roof (S)	Louvres/Roof (S)
	2	Glazing (S)	Glazing (S)
	3	Glazing (S)	Glazing (S)
Northern	1	Louvres/Roof (S)	Glazing (N)
	2	Glazing (N)	Louvres/Roof (S)
	3	Brickwork (N)	Glazing (N)
Western	1	Louvres/Roof (S)	Louvres/Roof (S)
	2	Glazing (N)	Glazing (N)
	3	Glazing (S)	Glazing (S)

Table 5 shows that the ranking at all locations, except the northern receivers, are identical between the two methods for the top three lowest performing building elements.

The discrepancy with the northern receivers is largely due to the increased sound power predictions for the glazed building elements when based on the analysis of the sound pressure measurements. With an increased level of the glazed windows and sliding doors, the impact from the rooftop louvres have been diluted. However, the contributions from the noise transmitting through the building elements toward the northern receivers are shown in Table 4 to be nearly equal.

CONCLUSIONS

A study was completed to determine the accuracy of ranking the acoustic performance of building elements using sound intensity measurements.

The results of the study indicated that sound intensity is a precise method for ranking acoustical performance of building elements. Comparing the ranked building elements using the sound intensity method against the sound pressure method yielded almost identical results, with the exception of one receiver group.

The approximated sound power due to the intensity measurements were found to be consistently lower than those predicted using the sound pressure method; with a disparity of up to 10dBA. It is likely that the intrusive impact of the most dominant rooftop louvre element was diluted at the northern receiver group due to increases in other building elements, such as fixed full height glazing and glass sliding doors along critical façades.

Considering the likely causes behind the disparity between the two methods at the northern receiver location, it is concluded that the ranking of acoustical performance and noise transmission through building elements using sound intensity is an accurate alternative to standard sound pressure measurement based rankings.

REFERENCES

Fahy, FJ 1995, *Sound Intensity*, 2nd edn, E & FN Spon, London.

Ginn, KB & Gade, S 2007, *Bruel & Kjaer – Sound intensity measurements inside a motor vehicle*, viewed 2 June 2012, <http://www.bksv.com/doc/bo0019.pdf>.

International Organisation for Standardization 1993, *Acoustics – Determination of sound power levels of noise sources using sound intensity – part 1: measurement at discreet points*, ISO 9614-1:1993, International Organisation for Standardization, Geneva.

International Organisation for Standardization 1996, *Acoustics – Determination of sound power levels of noise sources using sound intensity – part 2: measurement by scanning*, ISO 9614-2:1996, International Organisation for Standardization, Geneva.

Jacobsen, F & de Bree, HE 2005, 'A comparison of two different sound intensity measurement principles', *Journal of the Acoustical Society of America*, vol 118, no. 3, pp. 1510-1517.

Larson Davis Incorporated 1999, *Model 2260 Sound Intensity Probe*, viewed 3 June 2012, <http://www.larsondavis.com/docs/manuals/2260_Manual.pdf>.