The determining impact of architecture on sound in the built environment: Applications in sound masking systems and indoor noise sources

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1 Introduction

The field of Architectural Acoustics is predicated on the understanding that the built environment has a determining impact on the behaviour of sound. Yet, the effects of physical features (e.g., room shape, geometry, architectural finishings, furnishings, and fit-outs) on the spectral characteristics of sound are not always differentiated from those of measurement procedures (e.g., location of stationary and moving microphones).

Whereas a previous investigation sought to quantify the variation of sound within a spatial resolution that should be considered more academic than practical, the interest herein is to apply those conclusions and correlations to more context-relevant applications and scenarios, such as electronic masking sound and indoor noise sources [1]. Particular attention is directed to exploring the relation between performance-related parameters of a sound masking system (specifically, control zone size) and the masking sound *actually* delivered in the space.

2 Method

Architectural environment and sound masking system

The test area is a section of open-plan office space of approximately 118.5 m^2 (1275 ft^2) set within a larger facility; see Figure 1. The walls at the boundaries terminate at the ceiling (3 m or 10 ft), except at the top and left. The space incudes nine workstations with 1.67-m (65¾-in) partitions (featuring absorptive panels), as well as office equipment and furniture. The ceiling is acoustical tile (NRC 0.85) and the floor is carpeted. The roof deck is 8.3 m (27 ft). Due to the tall plenum, 18 loudspeakers are installed approximately 0.5 m (1.5 ft) above the ceiling, facing downward. Each is provided an independent signal generator and can be individually adjusted for overall sound level and one-third octave bands between 100 Hz and 10,000 Hz (the full Optimum Masking Spectrum [OMS] published by the National Research Council of Canada) [2]. The full range is important, as it impacts comfort and *acoustical* privacy (i.e., from noise and speech). Loudspeakers can also be adjusted as part of a group, or control zone, of varying sizes.

Unlike other acoustical treatments, the 'product' is not the hardware. Rather, it is the masking sound delivered to the space, which ought to be temporally constant, spectrally balanced and spatially consistent—attributes that depend on the control zone parameters (treatment area and size, number of loudspeakers). Typical design guidelines include loudspeaker center-on-center spacing (e.g., 3 m [10 ft] to 4.6 m [15 ft]) and ensuring zones only cover similar spaces—both architecturally (e.g., geometry, finishings, furnishings)

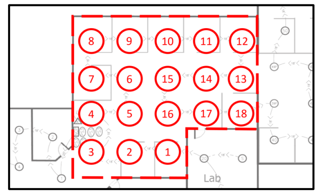

Figure 1: Boundaries of measurement test area. Circles identify 18 loudspeakers, as well as measurement locations. The three-LSCZ are 1-2-3, 4-5-16, 7-8-9, 10-11-12, 6-14-15 and 13-18-17. The six-LSCZ are 1-2-3-4-5-16, 6-7-8-9-10-15 and 11-12-13-14-17-18.

and by function (e.g., meeting or focus room). To the extent possible, these 'best practices' are relied on here, when selecting control zone configurations having more than one loudspeaker. The test area was selected to permit division into one-, three-, six-, and 18-loudspeaker control zones (LSCZ). While groupings were selected with the intent of providing consistent outcomes, other configurations may prove more or less consistent.

Instrumentation and measurements

Two Class 1 sound level meters were used simultaneously, as an assurance against sources of error, including human, instrumentation, methodical, and unknown. A Class 1 sound calibrator was used.

A series of tests were conducted to determine the most appropriate testing method (i.e., stationary, sweep, circular, or spiral). Four 30-second measurements were made at each location to ensure individual points were statistically valid (complying with typical best practices in testing standards). Where measurements at a location were in disagreement, they were repeated. Differences between arithmetic averages of spectra were found to be insignificant (in the order of 0.1 dB).

Thus, the stationary method—four measurements at 1.3 m (4¼ ft), 60° altitude angle and separated by 30 cm ($11\frac{7}{8}$ in) (i.e., a square)—was selected for procedural efficiency. Measurements were conducted at contextually representative locations within the effective area of each loudspeaker.

These testing parameters are not to be confused with those in ASTM E1573-18, *Standard Test Method for Measurement and Reporting of Masking Sound Levels Using A-Weighted and One-Third-Octave-Band Sound Pressure Levels*. Where the Standard offers guidelines to assess 'Test Areas' up to 93 m^2 (1000 ft^2) in open-plan spaces (which may have one or more control zones), the intent here is to describe the spatial consistency at a greater, but still *practical* (i.e., controllable with a single-speaker zone), resolution within those 'Test Areas.'

Adjustment, or 'tuning,' of control zones

To minimize risk of noise interference, measurements were conducted afterhours and in the absence of occupants. Ambient conditions were closely monitored.

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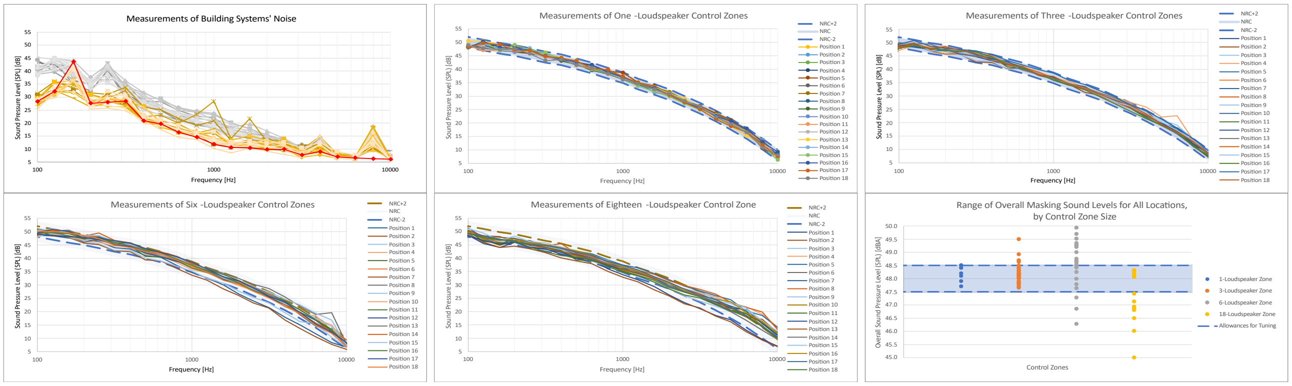

Figure 2: Charts are labeled from left to right, with (a) to (c) in the top row and (d) to (f) in the bottom row. Chart (a) shows noise from building systems. Charts (b) to (e) present the arithmetic average of four measurements at each location, for one-, three-, six and 18-LSCZ, respectively. Chart (f) presents the spread of overall sound levels of all locations for zones having different numbers of loudspeakers.

Testing of locations followed tuning of all control zones—i.e., requiring that each zone be tuned to compliance: an overall masking sound pressure level (SPL) within ±0.5 dBA and ±2 dB for all spectral bands in the OMS.

3 Results

Background noise

Noise from building systems were measured to ensure they did not interfere with the tuning process. Chart (a) in Figure 2 shows ambient measurements at all locations. Measurements were performed with building systems (i.e., HVAC) functioning (Case 1, grey data) and turned off (Case 2, yellow data). The averaged overall sound pressure level for Case 1 and 2 is 36.6 dBA and 30.3 dBA respectively. The 6 dB difference in level (and spectral differences) is significant—perceptually, and, especially, when assessing speech privacy. The light fixtures produced tones at 4,000 Hz and 8,000 Hz, and were turned off for the remainder of testing; the data for one such location is shown in red.

Masking sound

In this investigation, a location is determined to be 'Out of Compliance' (OoC) when the average of its four measurements does not meet the OMS criteria within tuning allowances. Results are in Table 1 and Figure 2 and Figure .

Table 1: Summary of OoC statistics for locations, by LSCZ size.

No. of Speakers per Zone	Percentage of locations OoC	Overall Level Difference µ (min.-max.)	Spectral Level Difference µ (min.-max.)
1	0/18 = 0%	–	–
3	4/18 = 22%	1.0 (0.7–1.5)	2.6 (2.2–3.5)
6	17/18 = 94%	1.1 (0.5–1.9)	2.7 (2.2–4.0)
18	16/18 = 89%	1.4 (0.5–3.0)	3.4 (2.3–5.1)

4 Discussion & Conclusion

The results of this investigation are specific to the tested area. Its architectural details—e.g., high absorption, taller-than-typical workstation partitions, number of loudspeakers, and sound masking system design—could have allowed for more consistent results than what may be possible in other spaces. Such differences in architectural factors will impact the propagation of sound (i.e., spectral and level variations) and may make it more, or less, challenging to control the consistency of masking sound. In other environments, there have been documented reports of larger variations across areas covered by larger control zones.

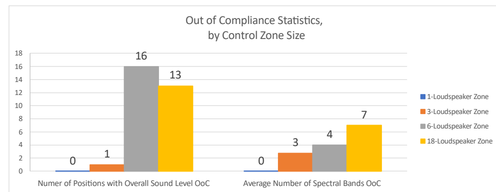

Figure 3: OoC statistics for level and spectrum, by LSCZ size.

At locations within larger LSCZ, architecture caused level differences larger than the tuning allowances; no set of adjustments could bring spectral bands (and/or overall sound level) within limits at each location. This was also true for the three-LSCZ [1-2-3], which was sufficiently variable, architecturally, to push location 3 OoC, reinforcing the need for LSCZ to be limited to similar spaces.

Where the outcome of six- and 18-LSCZ may appear similar, it cannot be interpreted to mean the larger zone offers better or comparable control or performance. Rather, the architectural parameters of this particular space led to those outcomes by chance. It is noteworthy that neither six- nor 18-LSCZ performed better than 89% OoC.

The size of control zones clearly influences the degree of variation in masking sound level and spectrum across an area. The results demonstrate that smaller zones—when tuned individually—enable improved localized control of sound and greater consistency across the facility.

References

[1] V. Koukounian, "A systematic investigation to assess the merits of measurement preconditions critical to speech privacy standards," *The Journal of the Acoustical Society of America,* vol. 151, no. 4, 2022.

[2] J. S. Bradley and B. N. Gover, "RR-262: Development and evaluation of speech privacy measurement software: SPMSoft," National Research Council Canada - Conseil National de Recherches Canada (NRC-CNRC), Ottawa, ON, Canada, 2008.