ACOUSTIC LAB PROJECT

Lab Results Technical Report

Acoustic Measurements From Different Rooms

Joseph Byrne

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Co-worker: Alan Chen

Supervisor: Dr Yusuke Hioka

Department of Mechanical and Mechatronics Engineering
The University of Auckland

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Contents

1 Relevant Specifications of Equipment Used **2**
- 1.1 Loudspeaker Characteristics & Properties 2
- 1.2 Microphone/ADC Characteristics & Properties 2

2 Noise Level in the Given Client Rooms **3**

3 Frequency Response of Given Client Rooms **5**

4 Analysing Reverberant Properties of Client Rooms **7**

5 Speech Intelligibility of Client Rooms **10**

6 Client Summary and Recommendations **11**

References **12**

Appendix A MATLAB Code **13**
- A.1 req1.m 13
- A.2 req2.m 13
- A.3 req3.m 14
- A.4 req4.m 15
- A.5 req5.m 16

Appendix B Plots and Images **18**

1. Relevant Specifications of Equipment Used

Following are the properties (for each respective device - speaker, ADC and microphone) of interest to the client.

1.1 Loudspeaker Characteristics & Properties

- No. of drivers: 2
- Frequency Range: 50 - 20000 Hz

1.2 Microphone/ADC Characteristics & Properties

- Principle: Condenser microphone
- Directivity: Omni-directional
- Frequency range: 20 - 20k Hz
- Sampling rate: 48 kHz
- Bit rate: 24-bit ADC

N.B: See Appendices (figures B1 & B2) for relevant frequency responses of both above-mentioned acoustic devices.

2. Noise Level in the Given Client Rooms

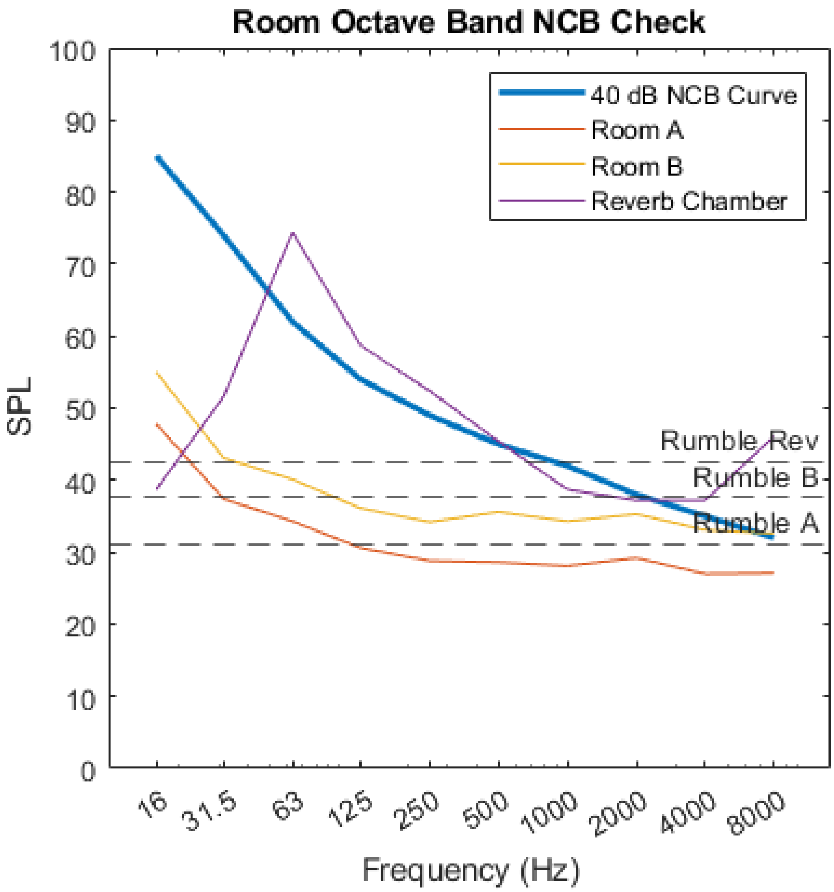


Figure 1 Noise balance criteria (NCB) curve. This curve described the nature of the staedy background noise in a given room, and can help an acoustic engineer classify a room for use.

Both room A and B NCB curves are (for the most part) below the 40dB NCB curve. Using impartial acoustic metrics such as rattle, vibration, hiss and rumble we may objectively classify a room's steady background noise.

In the case of both rooms, no rattle nor vibration is present. However, there is both rumble and hiss present in both rooms - thus, they are unbalanced. If rumble is present in a room, this means that the lower frequency components of the noise in the room is disproportionately high compared to the other higher frequency components. The same is true for hiss in high frequencies. Thus the low frequency content of the ambient noise in both rooms A and B is inadequately controlled. The same goes for the high-frequency content.

Speech Interference Level (SIL) is a parameter calculated and used to characterize a signal's level of interference in the frequency range where the human ear is most sensitive. The SILs for rooms A and B are 28.23dB and 34.58dB respectively - which are fairly low. Concerning the reverberation chamber - there is a significant imbalance; hiss, rumble and vibration are all present. It's SIL is much larger than the client rooms - 42dB (N.B: that dB is a log-scale [1]). This is because, though the room itself is completely acoustically isolated from external vibration, we simulated background noise in the lab.

Regarding full-band measurements, one can observe the clear discrepancies between the left and right plots below. From figure B3 we find that the A-weighting behave similarly to a pass-band filter, removing high and low-frequency components from the signal. This is true for both A-weighted signals below. As a result, the shape of the curve has changed significantly - in both instances - from the original Z-weighted signal. One may also observe a greater presence of noise in room B (figure 3) than A (figure 2) in both dBA and dBZ plots. This is simply due to the nature of the positioning of both rooms relative to the nearby road.

Overlaying our given NCB curves on the generic NCB plots provides us with a generally accurate estimation of the rooms' applications for different purposes (figures B4 & B5). Referring to figure B5, we find that both rooms are suited to very similar purposes:

- Room A: NICU (and below)
- Room B: Operating Rooms (and below)

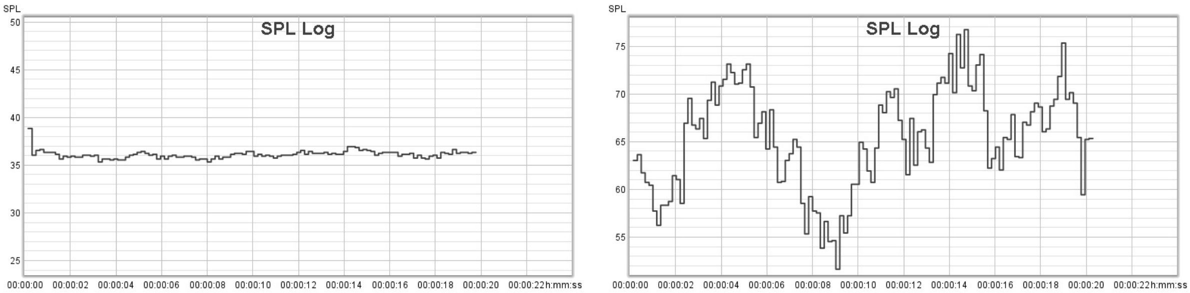


Figure 2 Full-band sound level measurements of room A. SPL [dBA] (left) and SPL [dBZ] (right).

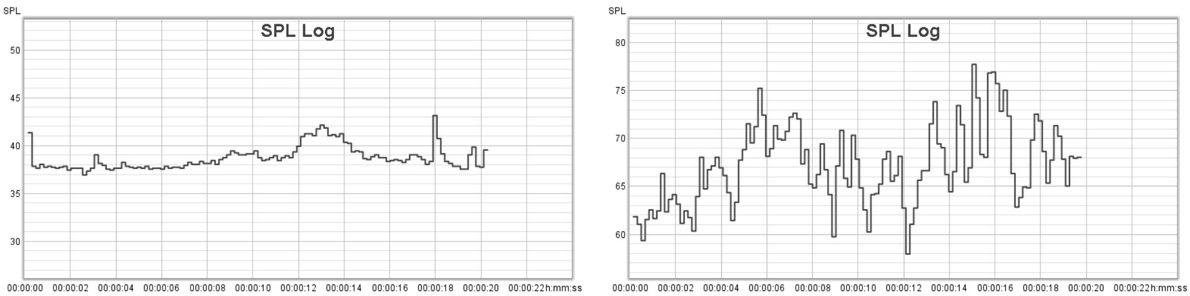


Figure 3 Full-band sound level measurements of room B. SPL [dBA] (left) and SPL [dBZ] (right).

3. Frequency Response of Given Client Rooms

To retrieve the frequency responses for analysis, we needed to use both aforementioned microphone and speaker. To determine the full-band frequency response across such a large frequency domain, it was necessary to attain the rooms impulse response to swept sine input, and subsequenty remove the speaker's own impulse response. A swept sine input is a signal which ramps up in frequency, ideally encapsulating all frequencies relevant to the human ear in a short space of time.

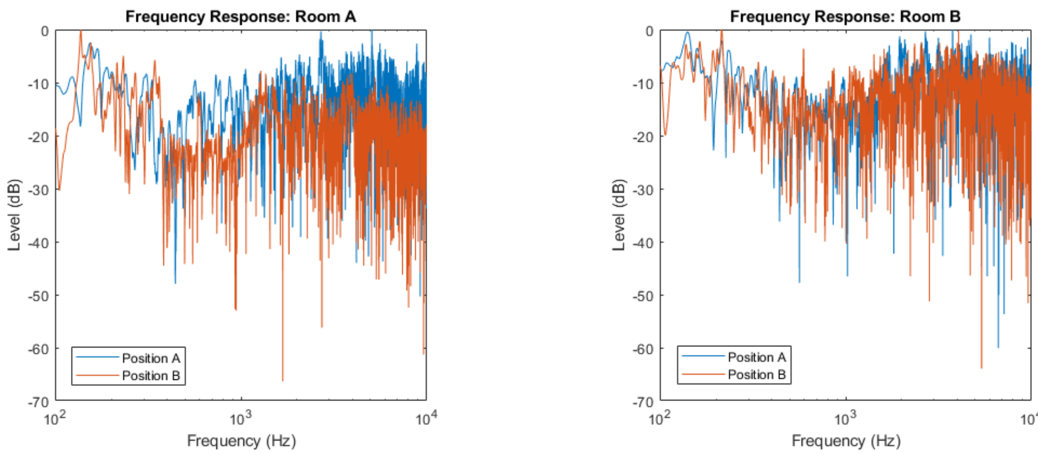


Figure 4 Frequency response (normalised) for both given positions in both rooms A (left) and B (right) (with 0^o speaker characteristics removed). The two positions are equidistant from the sound source.

A brief description of the rooms relative to one another (figure 5):

- Room A is far smaller in size, and a touch more anechoic than its counterpart. It is also situated in a relatively quiet area.
- Room B is a lot larger in size, and slightly more reverberant (figure B6). It is situated in a busier region.

Changing the microphone's position seems to have a greater effect on the frequency response in room A than in B (figure 4). This is characterised by a greater drop in amplitude across the specified frequency range in position B than in position A. Because of the considerable size difference between rooms A and B, moving the source to a new position in room A will have a far greater impact on the measured frequency response.

This difference is due to the directionality of higher-frequency signals [2]. Higher-frequency sounds are more directional than low-frequency sounds, and thus harder to reflect. In the position closer to the wall, the microphone is receiving higher power reflections of the high-frequency components of the swept-sine and thus has a greater amplitude response at greater frequencies than in the position further from the wall.

The difference between the rooms - or lack thereof - can be explained simply by comparison of each room's primary materials, and their acoustic properties respectively. Each room uses acoustic plaster (for the most part) - see [3] for acoustic properties of this material. In room B there is a section which is tiled (figure B7), which leads to a slightly higher reverberant property [1]. However, for the most part both room's relevant acoustic surface area is covered in the same material. Thus, the acoustic response (frequency response) from room-to-room is quite similar.

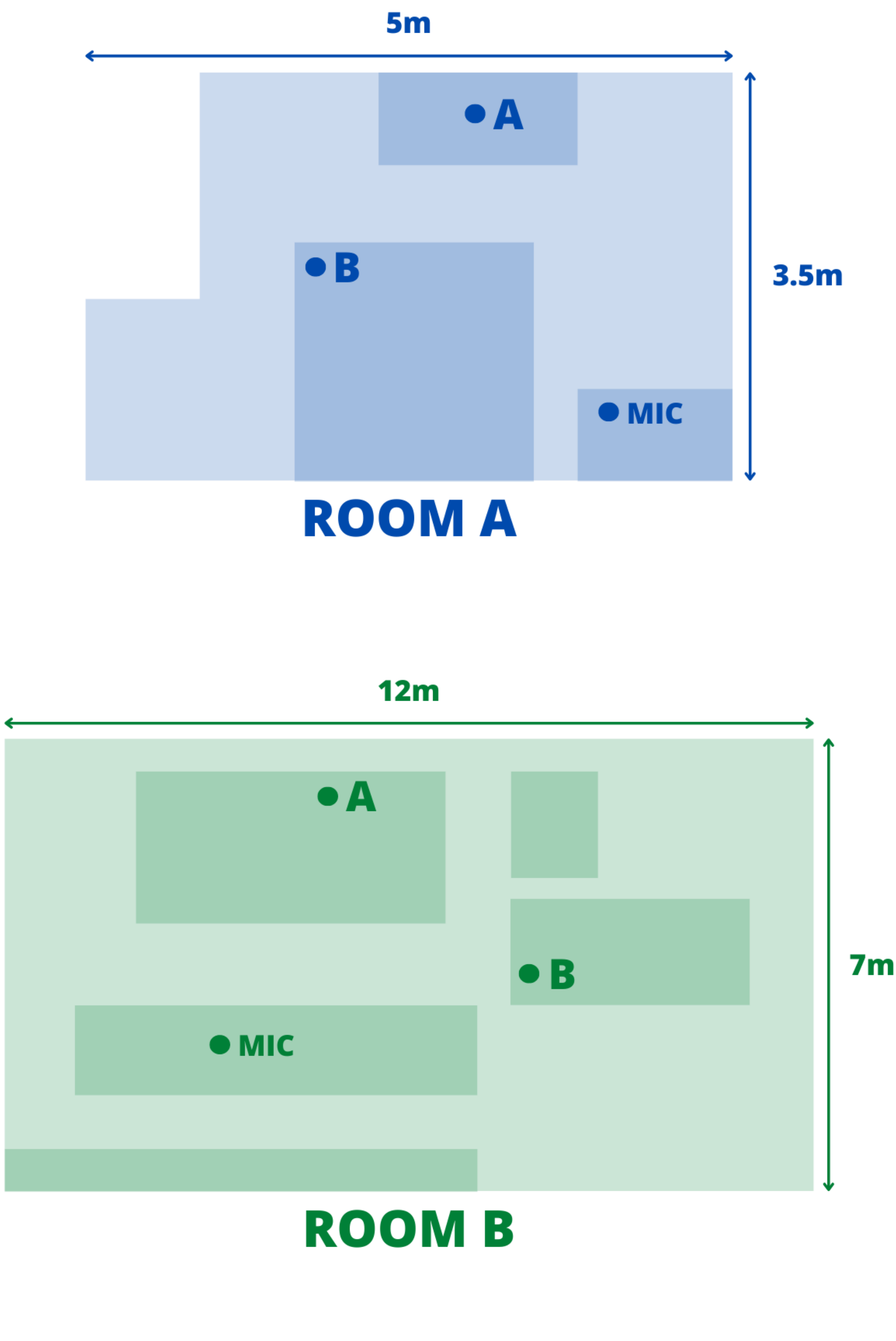


Figure 5 Rooms A and B layout, given positions A and B and the microphone's position relative to these positions (microphone placed at 0^o). See figure B7 for reference photos of the two rooms.

4. Analysing Reverberant Properties of Client Rooms

A rooms impulse response (RIR) can be separated into 3 key sections - direct sound, early reflection and late reverberation (figure 6). It is desirable - for analysis purposes - to discern the ratios of these different components to one another. Analysing these ratios can grant insight into the acoustical qualities of a given room.

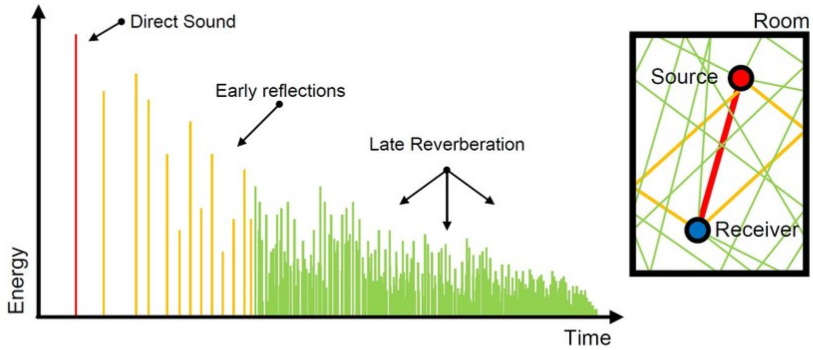


Figure 6 Standard room impulse response decomposed into relevant sections. Retrieved from [4].

The early decay curve of a room is a tool acoustic engineers may analyse the reverberant properties of said room. It can be computed using equation 1 (substituting integration for summation within a relevant range for digital signals).

$$EDC(t) = 10log_{10}\int_{t}^{\infty} h^2(\tau)\, d\tau \tag{1}$$

Secondly, to compute the relevant reverberation times (20ms Time and Early Decay Time) for our given room the following methods may be used.

- EDT: linear regression using 0dB and -10dB EDC indices
- T20: linear regression using -5dB and -25dB EDC indices

From initial inspection, the EDC shape (figure 7) - in each of the above graphs - is familiarly 'sigmoidal' (which is to be expected). Linear regressions produced from the above EDCs inform the EDT and T20 curves for each of the third-octave band center frequencies (figure 8). EDT and T20 were selected as they provide short-form estimations of the RT without the low background-noise-floor requirements to compute the likes of T60 or similar [1] [5]. The reverberation times (RTs) produced are sensical with respect to the nature of the rooms which they represent. One may observe variation in RT between the positions in both spaces. This is because in generally less reverberant environments, one may expect greater changes in RT when changing position. Even with a positional change as minor as what we made in our experiments, clear variations in the RTs are observed. Secondly, generally, room B's RTs seem slightly greater than A's - which is consistent with figure B6's depiction.

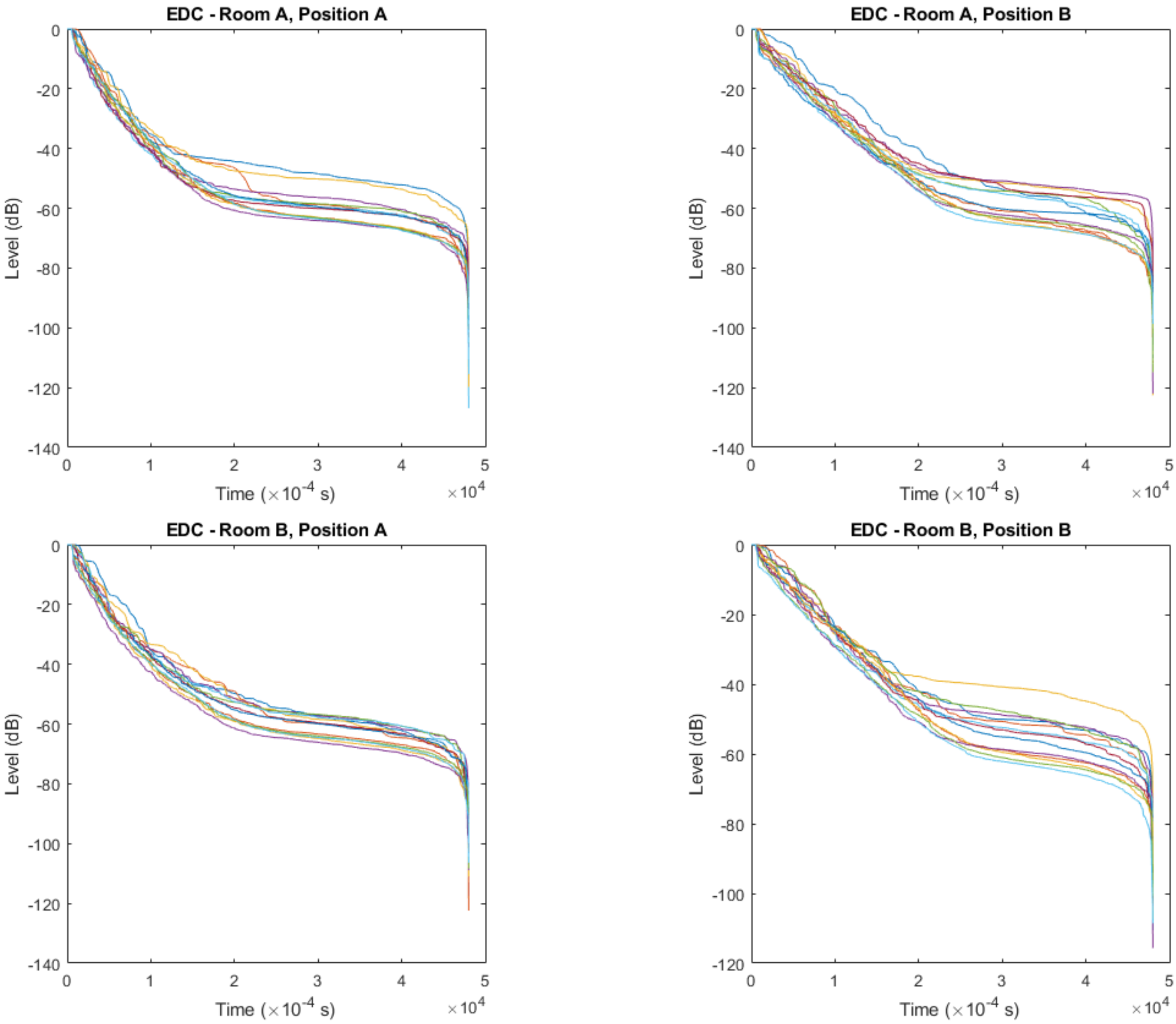
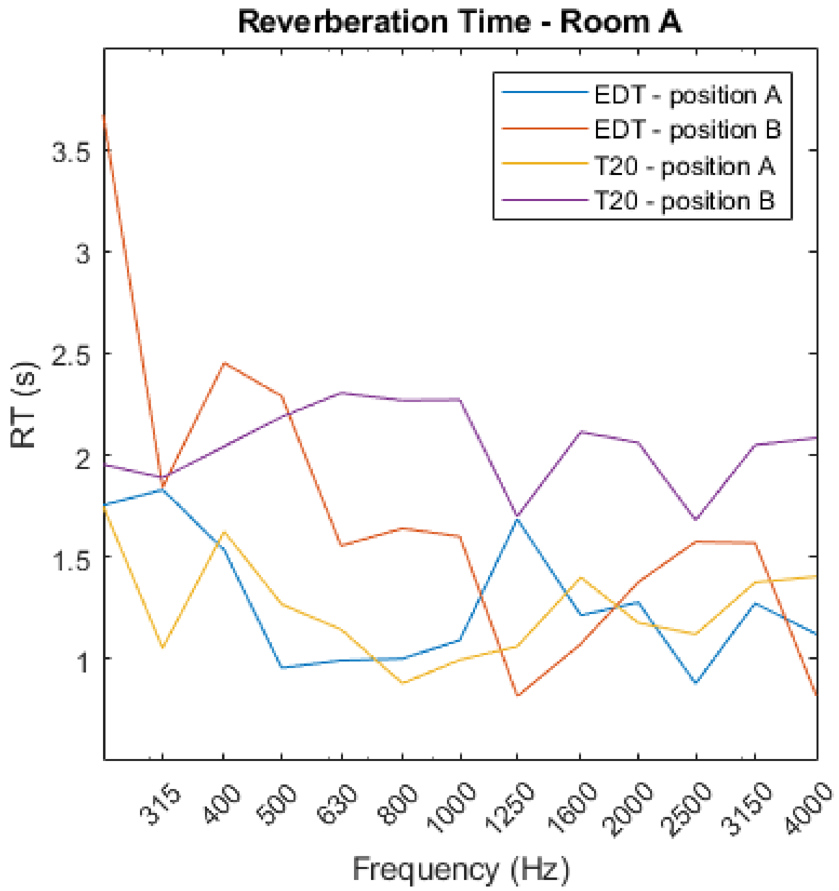


Figure 7 Early Decay Curves (EDC), for each position, in each room, at each third-octave band center frequency within a 250 - 4k Hz range.

Moreover, for the most part, it can be concluded that RT reduces with increasing frequency. At greater center frequency values one may observe a decrease in RT for both EDT and T20. This is once again due to the relationship between frequency and directionality. At higher frequencies, the reverberation is less noticeable and thus has a reduced effect on the reverberation time.

The RTs computed and plotted in figure 8 are reasonable compared with standard measured RTs of domestic rooms (N.B: the client-provided rooms are domestic in nature) [6]. No known outlying conditions or boundaries exist for either rooms. As such, we can proceed to further analysis.



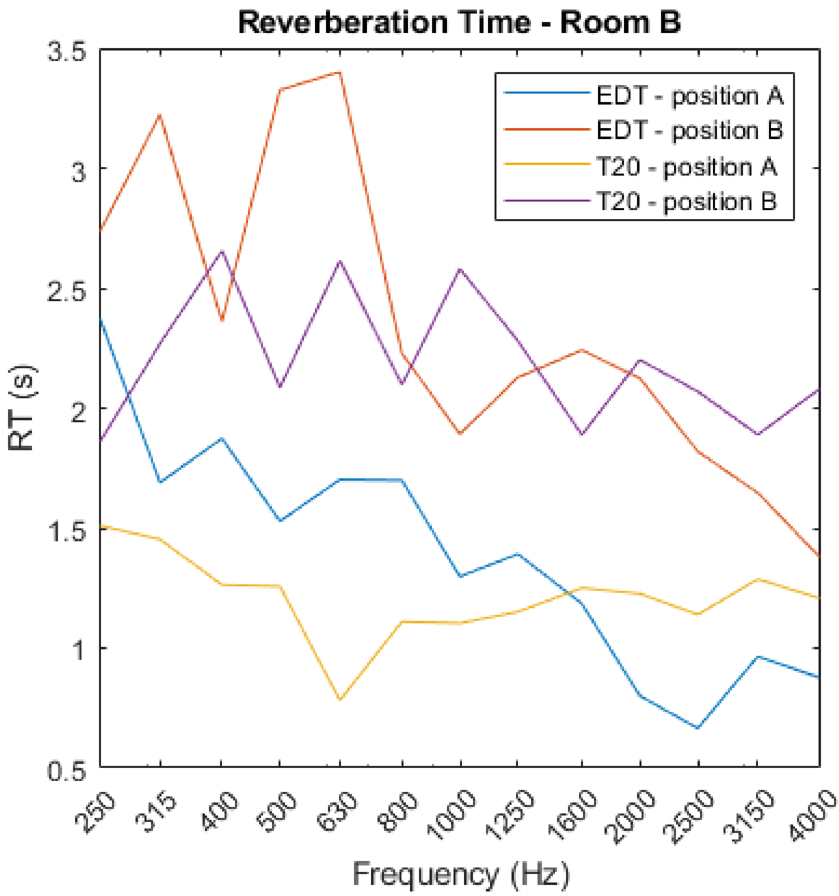


Figure 8 Early Decay Time (EDT) and T20 reverberation times calculated for both rooms from linear regressions produced using the above EDCs.

5. Speech Intelligibility of Client Rooms

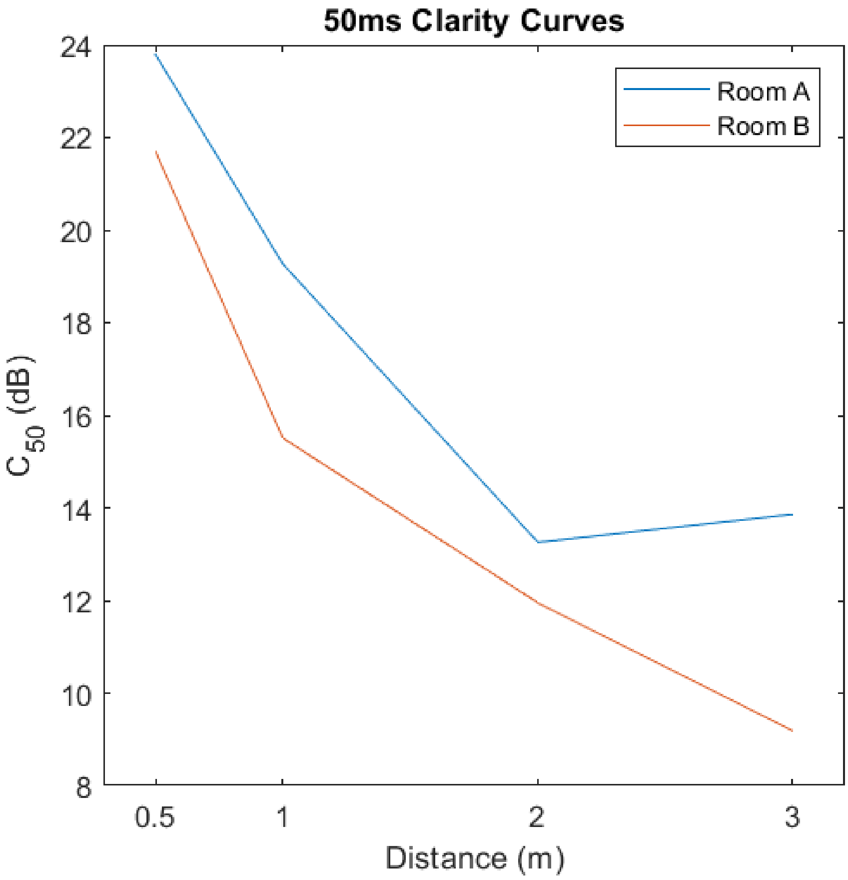


Figure 9 50ms Clarity curves describing the clarity at the given array of distances in both rooms.

50ms Clarity (C50) can be calculated using equation 2, and describes the ratio of the short-field impulse response and far-field impulse response in the time domain [7]. Because room A is less reverberant, the power of the impulse response's direct signal is far stronger relative to any secondary reverberant response. Thus, the ratio for each of the center frequencies is understandably higher in a less reverberant environment. This is consistent with most domestic (and otherwise) environments [8].

$$C_{50} = 10log_{10}\frac{\int_0^{50ms} h^2(t)\,dt}{\int_{50ms}^{\infty} h^2(t)\,dt} \tag{2}$$

Secondly, the clarity clearly reduces with increased distance from the source, this is also fairly common in most environments [9]. This is expected, mainly as the 50ms window captures less and less of the initial impulse signal. As such, the ratio value decreases with increasing distance - as observed in the above graphs (figure 9).

The 3m reading for clarity in room A seems to be just that. It may be due to noise in the impulse response reading. The square of the sum could accentuate the noise in the direct (50ms) signal, which may result in a higher reading.

6. Client Summary and Recommendations

To finalise the recommendation for the client, it is worthwhile reiterating some of the key observations made throughout this investigation. It is clear that each of the client rooms perform very close to standard operation for most rooms of this type. Though unbalanced (and I acknowledge that balance is binary), it can be argued that because of the minority of the imbalance, the rooms are fairly desirable for most applications (aside from auditorium or other extreme use). The SIL values are decidedly low, and A-weighted full-band measurements (dBA) are fairly consistent in both rooms. While Room B garners a slightly more boisterous room recommendation, both rooms are suitable for the given examples as well as other (such as small rehearsal rooms,meeting or conference rooms, or classrooms and libraries - to name a few).

Aside from their broad application, these rooms exhibit a frequency response fairly consistent with one another's, and as such makes them perhaps even further interchangeable. The changes in reverberation times between rooms and positions are consistent with the literature and indicate a fairly acoustically stable space. Moreover, the clarity, though exhibiting a decrease with distance, reduces at a far slower rate than in other environments (see [9]).

Thus, both client-provided rooms have satisfied the standard requirements of any standardised room acoustical tests. To conclude, these spaces come highly recommended from an acoustic standpoint for any of the above mentioned purposes.

References

[1] F. A. Everest and K. C. Pohlmann, *Master handbook of acoustics*. McGraw-Hill Education, 2022.

[2] M. B. Calford and J. D. Pettigrew, "Frequency dependence of directional amplification at the cat's pinna," *Hearing research*, vol. 14, no. 1, pp. 13–19, 1984.

[3] D. Lindeberg, "Acoustical plaster in construction," Feb 2018. [Online]. Available: https://www.dsfinishes.com/ds-blog/2017/4/20/acoustical-plaster-just-got-evenbetter

[4] S. Pelzer, L. Aspöck, D. Schröder, and M. Vorländer, "Integrating real-time room acoustics simulation into a cad modeling software to enhance the architectural design process," *Buildings*, vol. 4, no. 2, pp. 113–138, 2014.

[5] K. Jambrosic, M. Horvat, and H. Domitrovic, "Reverberation time measuring methods," *Journal of the Acoustical Society of America*, vol. 123, no. 5, pp. 3617–3617, 2008.

[6] C. Brunsgaard, P. Heiselberg, M.-A. Knudstrup, and T. S. Larsen, "Evaluation of the indoor environment of comfort houses: Qualitative and quantitative approaches," *Indoor and Built Environment*, vol. 21, no. 3, pp. 432–451, 2012.

[7] D. H. Griesinger, "What is" clarity", and how it can be measured?" in *Proceedings of Meetings on Acoustics ICA2013*, vol. 19, no. 1. Acoustical Society of America, 2013, p. 015003.

[8] L. G. Marshall, "An acoustics measurement program for evaluating auditoriums based on the early/late sound energy ratio," *The Journal of the Acoustical Society of America*, vol. 96, no. 4, pp. 2251–2261, 1994.

[9] J. Harvie-Clark and N. Dobinson, "The practical application of g and c50 in classrooms," in *Inter-noise and noise-con congress and conference proceedings*, vol. 247, no. 7. Institute of Noise Control Engineering, 2013, pp. 1510–1520.

[10] B. Gracey, "Acoustic glossary." [Online]. Available: https://www.acoustic-glossary.co.uk/frequency-weighting.htm

[11] J. Quartieri, C. Guarnaccia, S. DâAmbrosio, and G. Iannone, "Room acoustics experimental study: characterization of the sound quality in a new built church," in *Proceedings of the 10th WSEAS International Conference on "Acoustics & Music: Theory & Applications"(AMTA'09), Prague (Rep. Ceca)*, 2009, pp. 23–25.

Appendix A MATLAB Code

A.1 req1.m

```matlab
% Close figures
close all;

addpath data\cali\

% Grab each impulse response .mat file
for ii = 1:4
    % Produce a new figure
    figure;

    % Grab .mat file
    filename = sprintf("deg%d.mat", (ii-1)*90);
    imp_resp = load(filename).y(4.75e4:9.55e4);

    % Calculate freq. resp. using FFT
    freq_resp = abs(fft(imp_resp));
    freq_resp = freq_resp(1:floor(length(freq_resp)/2));

    freq_resp = 20*log10(freq_resp);

    % Plot the freq. resp.
    freq_range = 100:1e4;
    semilogx(freq_range, freq_resp(freq_range)); axis square
    hold on

    title(sprintf("Frequency Response (%d degrees)", (ii-1)*90));
    ylabel("Level (dB)");
    xlabel("Frequency (Hz)");

    hold off;
end
```

A.2 req2.m

```matlab
% Close figures
close all;

% Calibration factore from cali. file tests in anechoic chamber
CAL = -2.3;

% Octave band cent. freq. and readings
cent_freq = [16, 31.5, 63, 125, 250, 500, 1000, 2000, 4000, 8000];
dB40 = [85, 74, 62, 54, 49, 45, 42, 38 ,35, 32];
room_a = [50.1, 39.7, 36.6, 32.9, 31.1, 30.9, 30.4, 31.5, 29.3, 29.4] + CAL;
room_b = [57.3, 45.4, 42.4, 38.4, 36.5, 37.9, 36.6, 37.6, 35.4, 34.9] + CAL;
reverb = [41  , 53.9, 76.7, 61  , 54.7, 47.7, 41  , 39.5, 39.5, 48.4] + CAL;

% SIL calc.
SIL_a = mean(room_a(6:9));
SIL_b = mean(room_b(6:9));
SIL_r = mean(reverb(6:9));

% Plot NCB curves
```

```
figure;
semilogx(cent_freq, dB40, "LineWidth", 2); axis square;
hold on;
semilogx(cent_freq, room_a);
semilogx(cent_freq, room_b);
semilogx(cent_freq, reverb);
yline(SIL_a+3, 'label', "Rumble A", 'LineStyle', '--');
yline(SIL_b+3, 'label', "Rumble B", 'LineStyle', '--');
yline(SIL_r+3, 'label', "Rumble Rev", 'LineStyle', '--');

xlim([10, 14e3]);
ylim([0, 100]);

xticks(cent_freq);

title("Room Octave Band NCB Check");
ylabel("SPL");
xlabel("Frequency (Hz)");

legend(["40 dB NCB Curve", "Room A", "Room B", "Reverb Chamber"]);
```

A.3 req3.m

```
% Close figures
close all;

addpath data\cali\
speaker_char = load("deg0.mat").y;

% Setup vars
rooms = ["a", "b"];
positions = ["a", "b"];

% Loops through each room and position
addpath data\feat2\
for room = rooms
    labels = [];
    figure;
    for pos = positions

        % Grab relevant file and thus imp. resp.
        filename = sprintf("imp_resp_%s_%s.mat", room, pos);
        imp_resp = load(filename).y(4.75e4:9.55e4) - speaker_char(4.75e4:9.55e4); % Correct way of accounting for?
        freq_resp = abs(fft(imp_resp));
        freq_resp = freq_resp(1:floor(length(freq_resp)/2));

        % Get max for normalising
        max_gain = max(freq_resp);
        freq_resp = 20*log10(freq_resp/max_gain);

        % Plot freq. resp.
        freq_range = 100:2e4;
        semilogx(freq_range, freq_resp(freq_range)); axis square

        hold on

        xlim([100 1e4])
        title(sprintf("Frequency Response: Room %s", upper(room)));
        ylabel("Level (dB)");
        xlabel("Frequency (Hz)");
```

```

        labels = [labels sprintf("Position %s", upper(pos))];

    end
    legend(labels);
    hold off;
end
```

A.4 req4.m

```
% Close figures
close all;

% Set up vars
third_cf = [250, 315, 400, 500, 630, 800, 1000, ...
    1250, 1600, 2000, 2500, 3150, 4000];
rooms = ["a", "b"];
positions = ["a", "b"];

% Loops through each room and position
addpath data\feat2\
for room = 1:length(rooms)
    % Set up and reset iterable matrices
    EDT = zeros(length(positions), length(third_cf));
    T20 = zeros(length(positions), length(third_cf));
    for pos = 1:length(positions)

        % Grab relevant file and thus imp. resp.
        filename = sprintf("imp_resp_%s_%s.mat", rooms(room), positions(
            pos));
        imp_resp = load(filename).y(4.75e4:9.55e4);

        % Open new fig.
        figure;

        % Set up relevant vars
        EDC = [];
        labels = [];
        y = [];

        % Loop through third octave band freq.
        for cf = 1:length(third_cf)
            % Produce third octave-band passband filter bank
            [B,A] = oct3dsgn(third_cf(cf), 4.8e4, 3);
            y = filter(B,A,imp_resp);

            % Compute EDC using filtered imp. resp.
            for kk = 1:length(y)
                EDC(kk) = sum(y(kk:end).^2);
            end

            % Normalise
            EDC = 10*log10(EDC/max(EDC));

            % Calc. RT
            EDT(pos,cf) = RTcalc("EDT", EDC);
            T20(pos,cf) = RTcalc("T20", EDC);

            % Plot EDCs
            plot(EDC); axis square; hold on;

```

```
            title(sprintf("EDC - Room %s, Position %s", upper(rooms(room
                )), upper(positions(pos))));
            ylabel("Level (dB)");
            xlabel("Time (\times10^{-4} s)");

        end
    end
    hold off;

    % Open new fig.
    figure;

    % Plot RTs
    semilogx(third_cf, EDT(1,:)); axis square; hold on
    semilogx(third_cf, EDT(2,:))
    semilogx(third_cf, T20(1,:));
    semilogx(third_cf, T20(2,:));
    hold off;

    title(sprintf("Reverberation Time - Room %s", upper(rooms(room))));
    ylabel("RT (s)");
    xlabel("Frequency (Hz)");

    xticks(third_cf);

    labels =   ["EDT - position A"
                "EDT - position B"
                "T20 - position A"
                "T20 - position B"];
    legend(labels);
end
```

A.5 req5.m

```
close all;

addpath data\feat4\

C50 = [];
labels = [];

distances = [0.5, 1, 2, 3];
rooms = ["a", "b"];

for room = rooms
    for dist = 1:length(distances)

        filename = sprintf("imp_resp_%s_%s.mat", num2str(distances(dist)
            ), room);
        imp_resp = load(filename).y(4.75e4:9.55e4);

        C50(dist) = 10*log10(sum(imp_resp(1:2400).^2)/sum(imp_resp(2400:
            end).^2));
    end
    plot(distances, C50); hold on

    labels = [labels sprintf("Room %s", upper(room))];
end

legend(labels); axis square
title("50ms Clarity Curves")
```

```
xlabel("Distance (m)");
ylabel("C_{50} (dB)");
xlim([0.3, 3.2]);
xticks(distances);
```

Appendix B Plots and Images

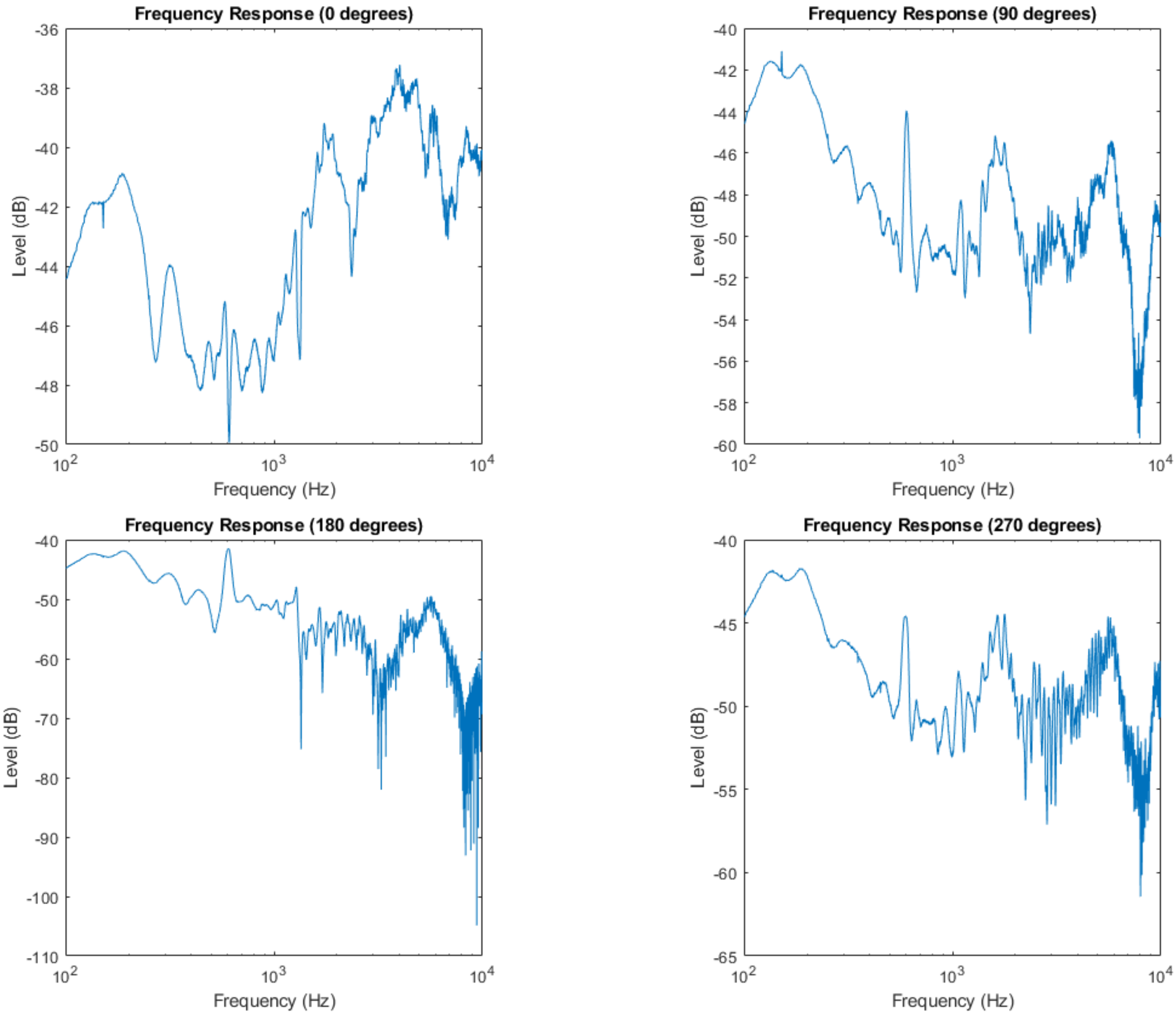


Figure B1 Frequency responses measured in the anechoic chamber at different speaker pose angles (azimuth) using a swept sine output signal. N.B: The frequency responses for both 90^o and 270^o have pseudo-identical frequency responses. Further, 180^o is the lowest in amplitude - which is sensical given this is the pose in which the source is pointed the furthest from the receiving microphone.

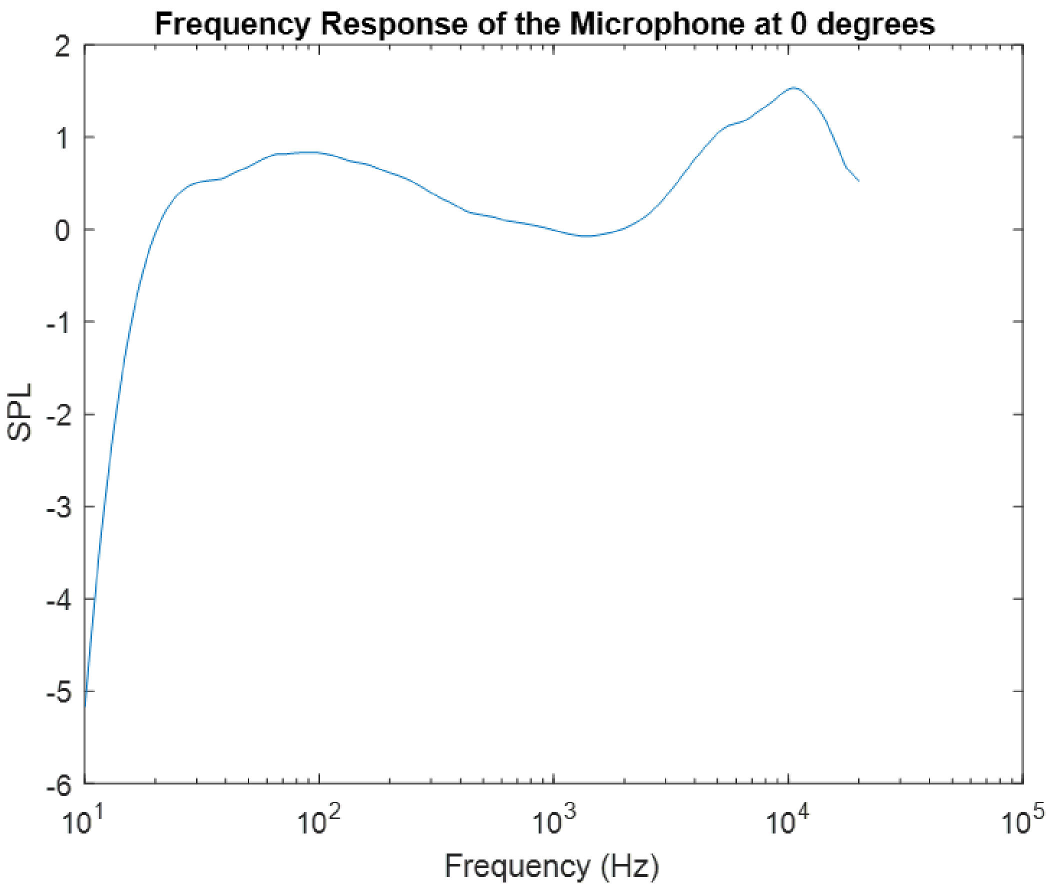


Figure B2 Frequency response of the UMIK microphone as supplied by its relevant calbiration file.

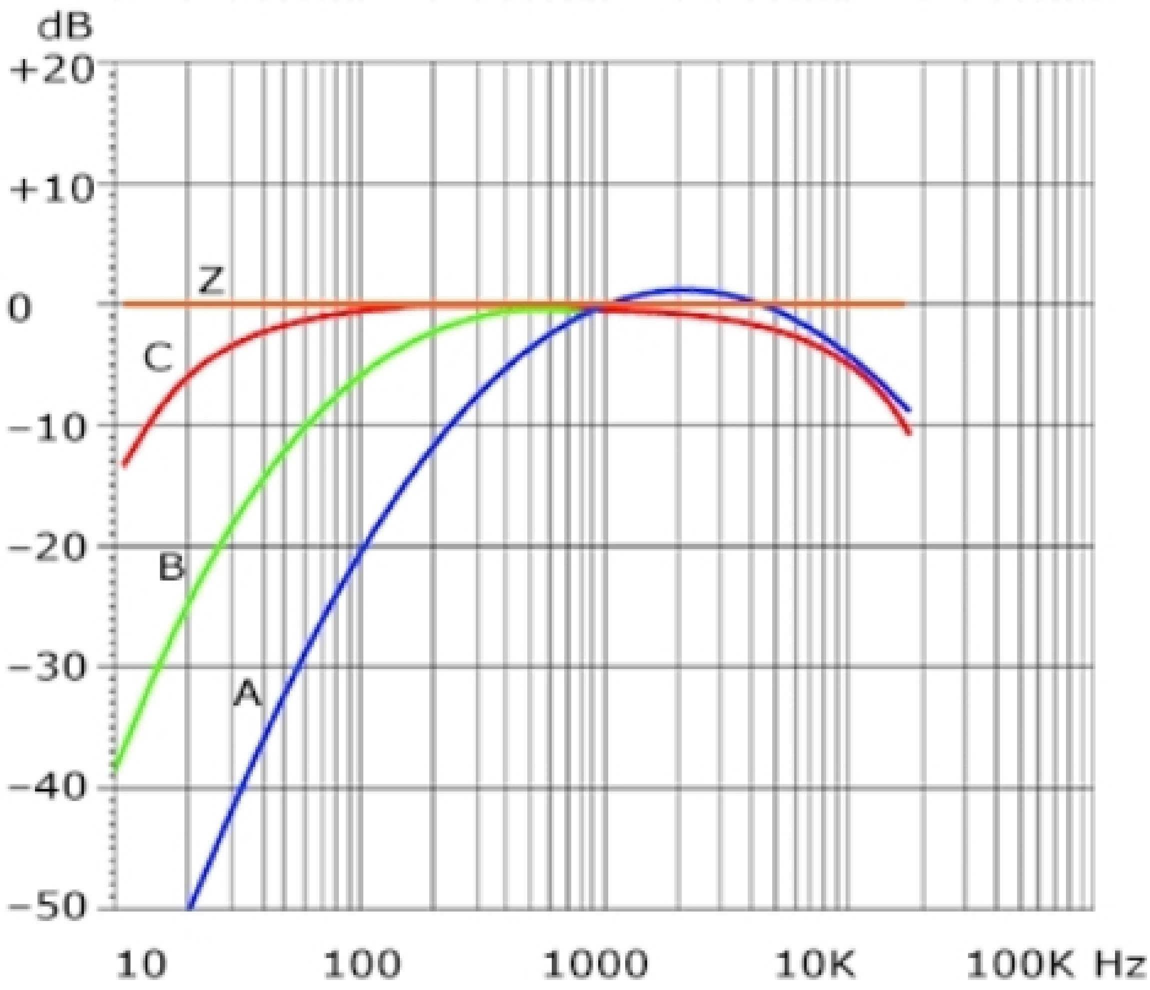


Figure B3 Frequency response of various sound-weightings. For purposes of this investigation, we use Z (orange) to display raw full-band measurements, and A (blue) to display the 'band-passed' filtered full-band measurements. Retrieved from [10].

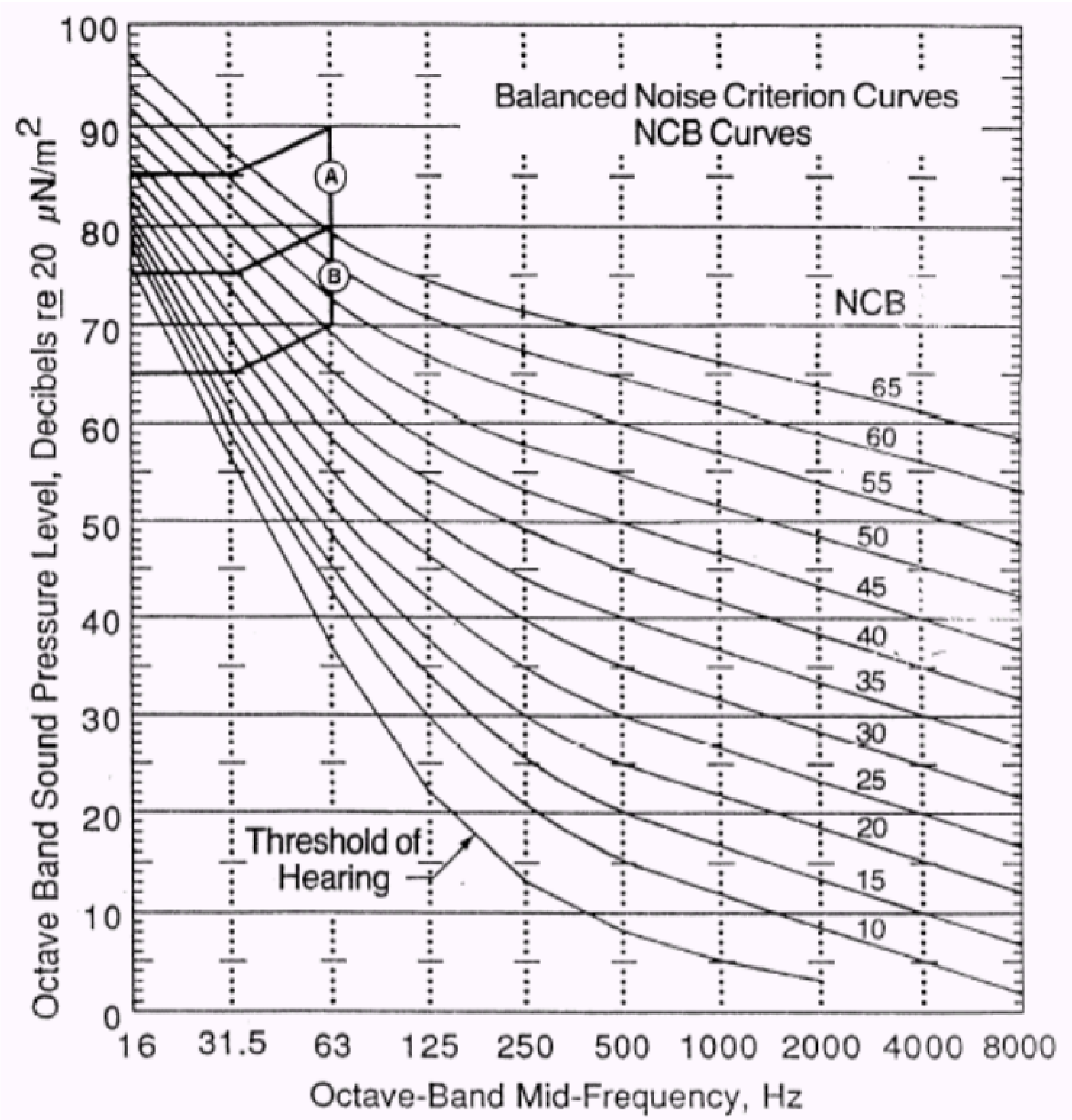


Figure B4 Balance Noise Criteria curves used for generic classifcation of rooms based on their ambient acoustic properties. Overlaying a rooms given NCB curve and approximating which curve it is closest to, can give a reasonable estimate for the room's suitability for an array of given purposes.

Room Type	NC / RC(N) /	dBA
Patient rooms	30-40	35-45
Multiple occupant patient care areas	35-45	40-50
NICU[1]	25-35	30-40
Operating rooms[2]	35-45	40-50
Corridors and public spaces	35-45	40-50
Testing/research lab, minimal	45-55	50-60
Research lab, extensive speech[2]	40-50	45-55
Group teaching lab	35-45	40-50
Doctor's offices, exam rooms	30-40	35-45
Conference Rooms	25-35	30-40
Teleconferencing Rooms	25 (max)	30
Auditoria, large lecture rooms	25-30	30-35

Figure B5 Classification mechanism used in tandem with the above curves to generalise and classify a room based on it's steady background noise.

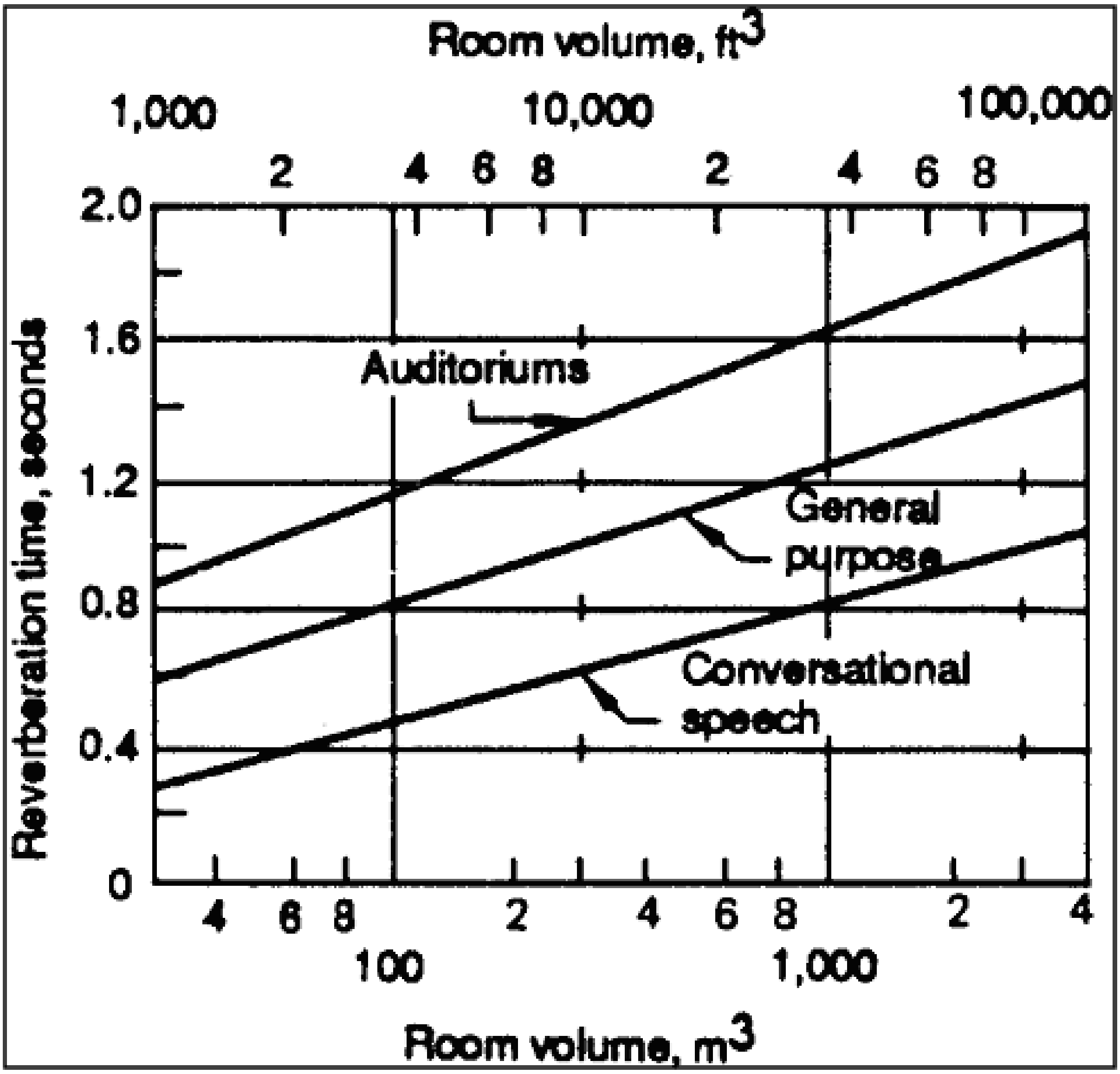


Figure B6 Relationship between Rt and room volume provided the absorption coefficient is below 0.35 (both client rooms satisfy this requirement [3]). For reference, the client rooms can be approximated to either of the bottom two curves. As you can see, reverberation time (and thus reverberation) goes up with room volume. Retrieved from [11].

Figure B7 Photographs depicting rooms A (top) and B (bottom). As you can see, room A is far smaller than room B.