Acoustics

Summative Assessment

"From Lecture to Concert"
An Impulse Response Study of Three University Rooms

Project Report

Exam number - B287055

List Of Contents

1. Introduction and Background

Acoustics are easy to overlook when a room works well, and very obvious when it doesn't: lectures start to sound muddy, music loses its detail, and background noise becomes the main thing the ear locks onto. This report looks at the acoustics of three rooms at the University of Edinburgh: the E22 lecture theatre in the ECA building, the A2 lecture room in Alison House, and St Cecilia's Hall concert room. E22 and A2 are used regularly for teaching on the programme, while St Cecilia's is a dedicated performance space with a longer history of renovation and adaptation. Together, they cover a range of typical situations, from large lectures to smaller classes and unamplified concerts, and provide a useful basis for comparing how different architectural choices affect sound in practice.

In this project, room impulse responses were measured in each space using a swept-sine method and a single impulsive excitation, in this case a handclap. For the swept-sine measurements, exponential sine sweeps of different durations were played through a loudspeaker and recorded with a stereo pair of Schoeps MK2S microphones, then deconvolved with the corresponding inverse sweep to obtain the impulse responses. The use of a stereo pair allowed left–right differences in early reflections and reverberation to be captured at each listening position. This follows Farina's swept-sine technique, which provides a high signal-to-noise ratio and gives reliable results under realistic noise conditions. In addition, impulsive responses were recorded using handclaps at comparable positions. Handclaps are quick and simple to perform and resemble the informal way people often "test" a room, but they tend to provide less low-frequency energy and are more sensitive to background noise. Comparing the results from the swept-sine and impulsive methods in the same rooms was a key part of the project, as it highlights the practical trade-offs between convenience and measurement quality.

A room impulse response describes how the sound field in a room evolves over time in response to a very short broadband signal at a specific source–receiver position, capturing the direct sound, early reflections and the late reverberant tail. From a single impulse response, standard room-acoustic parameters such as reverberation time and energy decay curves can be derived, and the point at which background noise begins to dominate the decay can also be seen. Reverberation time, defined as the time taken for the sound level to decay by 60 dB after the source stops, remains one of the most important descriptors, as it is closely related to whether a room feels relatively "dry" and speech-focused or more "live" and suited to music.

Although reverberation time is a central focus, other aspects are also important for how these rooms are used day to day. For the lecture spaces in E22 and Alison House, speech intelligibility is critical, so clarity measures such as C50 and the combination of mid-frequency reverberation with measured background sound levels are considered. For St Cecilia's Hall, a moderately reverberant response and a different clarity balance can be beneficial for unamplified music, and the hall's renovation history makes it interesting to see how those design decisions are reflected in the measured parameters. Simple comparisons of sound levels inside the rooms and in adjacent circulation spaces also give a basic indication of sound isolation. The aim of the report is to bring these elements together into a clear description of how the three rooms behave acoustically and how well that behaviour supports their intended functions.

2. Description of studied spaces

This project focuses on three rooms at the University of Edinburgh that represent different points on a spectrum from teaching to performance: the E22 lecture theatre in the ECA building, the A2 lecture room in Alison House, and St Cecilia's Hall concert room. They differ in size, geometry, surface finishes and intended use, and these differences are expected to be reflected in their measured acoustical behaviour.

2.1. St Cecilia's Hall Concert Hall

St Cecilia's Hall is an eighteenth-century concert room that now forms part of the University of Edinburgh's museum and performance facilities. The main concert room is an elliptical space used primarily for unamplified chamber music and recitals, with a small stage at one end containing a historic pipe organ and performance area. Seating is arranged in a central block with additional raised benches following the curve of the room, focusing attention towards the organ and stage.

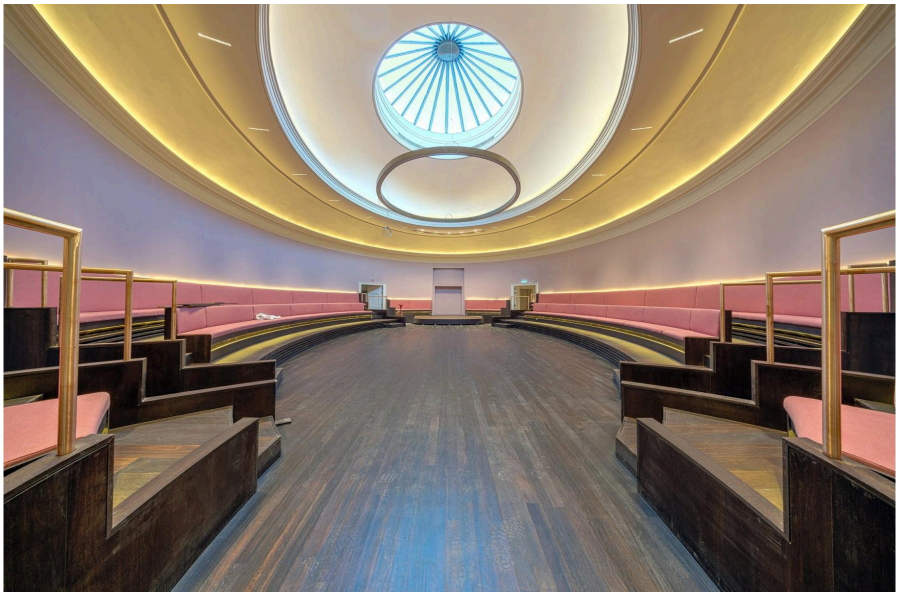

Figure 1 : Interior of St Cecilia’s Hall concert room, showing the elliptical plan, timber floor and domed ceiling.

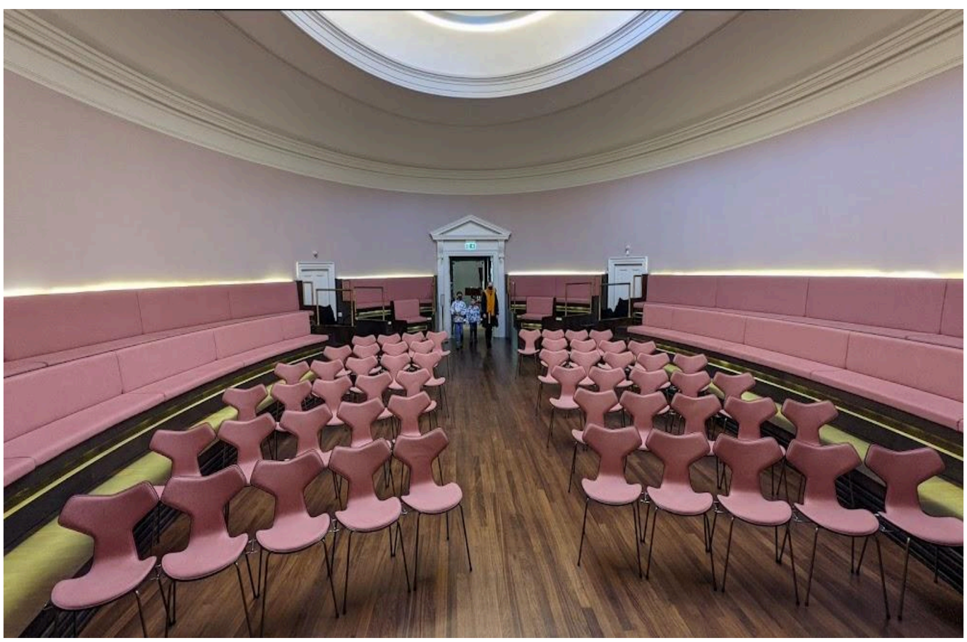

Figure 2 : The main audience floor is finished in timber, with movable upholstered chairs in the central area and padded bench seating around the perimeter. The walls and domed ceiling are largely hard, painted surfaces with relatively little visible acoustic treatment

The audience floor is carpeted, while the surrounding walls and the domed ceiling are largely hard, painted surfaces with relatively little visible acoustic treatment. The continuous curved walls and double-domed ceiling create a smooth, enclosing boundary, with architectural detailing rather than discrete absorbers or diffusers. Most of the absorption therefore comes from the audience and soft furnishings, rather than from dedicated acoustic panels. The hall has undergone several phases of renovation but has been restored to function again as a concert room, aiming for a balance between clarity and reverberant support for unamplified instruments. Within this project it serves as the “concert-end” reference: a space where a somewhat longer reverberation and a more enveloping sound field are desirable, and against which the more speech-oriented lecture rooms in E22 and Alison House can be compared.

2.2. E22 Lecture Theatre, ECA Building

E22 is a narrow, rectangular lecture theatre, just under 20.3 m long and around 8 m wide, with a ceiling height of approximately 6.88 m. The room is slightly longer than it is wide, with most of the seating arranged on a flat floor and the final third rising in eight stepped tiers at the rear. A fixed teaching desk and a shallow platform occupy the front of the room, where lectures and presentations normally take place. The seating capacity is roughly 170, with rows of individual upholstered chairs facing the teaching end.

Figure 3 : E22 lecture theatre viewed from the front–side, showing the seating layout, windows the stepped seating, carpeted floor and overall room geometry

2.3. A2 Lecture Room, Alison House

Figure 4: Alison House A2 lecture room

The A2 lecture room in Alison House is a medium-sized rectangular teaching space, approximately 11.6 m long, 6.77 m wide and 3.48 m high. Unlike E22, the floor is flat, and the seating is arranged in a more conventional classroom layout facing the teaching end of the room. The seating capacity is around 46, with students seated relatively close to the source compared to the larger lecture theatre. A grand piano is positioned near the entrance on the left-hand side, and a teacher's desk is located towards the right at the front of the room, reflecting its mixed use for lectures, seminars and practical music-related activities.

The floor is carpeted, and the walls appear to be constructed from plasterboard or similar panelled surfaces, finished in a smooth, painted treatment. Along one side of the room there is a slightly extended table used for refreshments or materials. Windows are located at the back of the room, providing natural light but also forming part of the reflective surface area. The ceiling incorporates three dome-like rectangular roof windows or light wells, with the surrounding ceiling surfaces again appearing to be hard plasterboard rather than dedicated acoustic tiles.

Compared with E22, the smaller volume, lower ceiling and greater proportion of carpeted floor and soft seating in A2 would be expected to result in a shorter reverberation time and a stronger direct sound at typical listening positions. This should generally favour speech clarity and make the room feel more controlled acoustically, even without extensive visible acoustic treatment. A2 therefore provides a useful contrast to E22 when comparing how similar teaching activities are supported in two rooms with quite different scales and geometries

3. Experimental Procedures Used

This section describes the measurement procedures used in the three rooms, including the excitation methods, room-specific setups, and the basic processing steps applied to obtain the final impulse responses and acoustic parameters.

3.1. Equipments

All measurements were carried out using the same core set of equipments:

I. **Genelec 8030A active loudspeaker**
Used as the sound source for all sine sweeps. This loudspeaker was chosen because it is a compact studio monitor with a relatively flat on-axis frequency response and low distortion, making it suitable for reproducing exponential sine sweeps without adding strong colouration of its own.

Figure 5 : Genelec 8030A loudspeaker

II. **Schoeps MK2S microphones (pair)**
A matched pair of Schoeps MK2S omnidirectional microphones was used to capture the responses in each room. These microphones were selected for their smooth frequency response, low self-noise and neutral off-axis behaviour, which are important for room-acoustic measurements. They were mounted as a stereo pair with approximately 49–50 cm spacing between capsules at typical seated ear height, so that each measurement captured both channels in a consistent configuration.

III.

Fig 6: Schoeps MK2S omnidirectional microphones

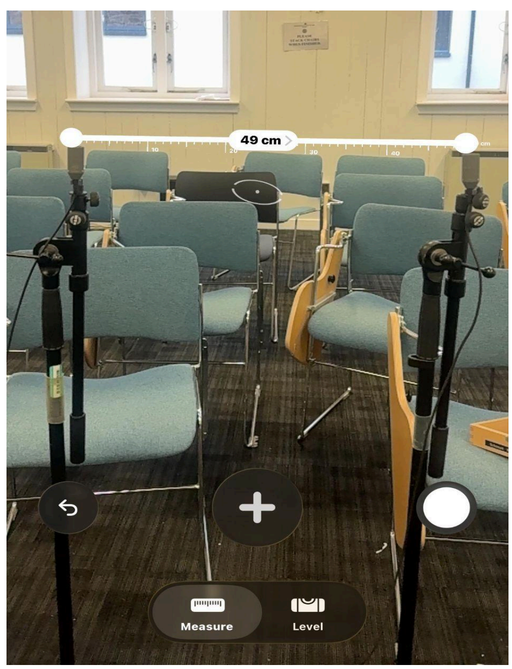

Fig 7 : Mics 49cms apart in Stereo XY configuration

A matched pair of Schoeps MK2S microphones was used as a 0.49 m spaced stereo pair at seated ear height. Recording stereo impulse responses (rather than mono) captures lateral differences between the ears, improving later auralisation possibilities, while averaging the two channels for RT and clarity metrics reduces local interference effects.

IV. **RME Fireface UCX II audio interface**
The RME interface handled playback of the sweep signals to the loudspeaker and recording of the microphone signals. It was chosen for its stable drivers, low-noise preamps and reliable clocking, helping to ensure clean recordings and accurate timing for the subsequent deconvolution and analysis.

Fig 8 :RME Fireface UCX II audio interface

This combination of monitor loudspeaker, high-quality omnidirectional microphones and a stable audio interface was intended to keep the playback and recording chain as neutral and repeatable as possible, so that differences observed in the results could be attributed mainly to the rooms and measurement methods rather than to the equipment.

V. **Optimus sound level meter**

This SPL meter was used to measure background noise levels in each room before the sweep recordings.

Fig 9 : Optimus Sound Level Meter

3.2. Experimental Procedures used

Measurements in all three rooms were based on exponential sine sweeps as the primary excitation, with additional impulsive measurements using handclaps. Before the sessions, sine sweeps of **5s, 11s and 20s** duration were generated at 44.1 kHz. On site, the choice of sweep length depended on the expected reverberation time and the **ambient noise level** in each room: shorter sweeps were used where the space was relatively quiet and the decay was short, while longer sweeps were preferred in noisier or more reverberant conditions to achieve a better signal-to-noise ratio in the tail.

For each chosen sweep configuration, **three takes** were recorded. The three takes were later averaged to even out small inconsistencies such as random noise, minor disturbances and slight level variations between repetitions. In all cases, the loudspeaker was placed at a representative source position (lecturer or performer), and the stereo microphone pair was positioned at typical listener locations.

I. **Alison House A2 lecture room**
In A2 a single source–receiver configuration was used. The loudspeaker was placed at the front of the room in a lecturer position, and the microphones were positioned approximately **6.5 m** away along the centre line. At this position, **11 s and 20 s** sweeps

were recorded, each with three takes, followed by a handclap. The 11 s sweep provided a good compromise between measurement time and SNR in this smaller, relatively quiet room, while the 20 s sweep allowed a check on whether a longer excitation brought any improvement in the decay detail, particularly at lower levels.

II. **E22 lecture theatre**
In E22, which is considerably larger and more prone to background noise, both sweep length and distance were varied. Sine sweeps of **5 s, 11 s and 20 s** were recorded at source–receiver distances of approximately **4.6 m, 7.7 m and 17 m** along the central axis of the seating. At each distance, three takes of the selected sweep were recorded. Shorter sweeps were used where the local noise level was lower or where time was limited, and the **20 s** sweep was used where the noise floor was more problematic, in order to keep the late part of the decay clearly above background. Handclap responses were also captured at comparable positions to provide impulsive measurements in the same large, noisy environment.

III. **St Cecilia’s Hall concert room**
In St Cecilia’s Hall the loudspeaker was placed at the performance end of the room near the organ and stage area, and the microphones were positioned in a representative audience location along the main axis. At this position, **5 s, 11 s and 20 s** sweeps were recorded, again with three takes for each sweep, followed by a handclap. Using all three durations in this more reverberant space made it possible to see how sweep length interacts with the longer decay and to compare the quality of the estimated RT and EDC when using shorter versus longer excitations.

3.3. Impulsive Measurements and Room EQ Wizard

For all impulsive measurements, *Room EQ Wizard (REW)* was used to analyse the handclap recordings. The recorded clap signals were imported into REW and treated as approximate impulse responses, from which *filtered IRs, RT60 estimates, C50 clarity values* and *spectrograms* were obtained. REW’s built-in processing was particularly useful when the captures were noisy, as it allowed windowing, filtering and decay analysis to be performed interactively and made it easier to see where the decay dropped into the noise floor.

REW was also used in conjunction with the sweep-based data. In addition to the MATLAB analysis, spectrograms and C50 values were generated in REW for the deconvolved sweep-based impulse responses, providing an independent view of the time–frequency behaviour and early-to-late energy balance in each room.

3.4. Post-Processing and Derived Parameters

For the sweep-based measurements, the recorded sine sweeps were deconvolved in MATLAB using the corresponding inverse sweep to obtain room impulse responses. For each configuration, the three recorded takes of the same sweep length were first deconvolved separately and then averaged in the time domain to produce a single representative impulse response. This averaging step helped to reduce random noise and even out small inconsistencies between takes, which was particularly important in the noisier environments such as E22. The averaged impulse responses were then time-aligned, normalised and truncated to appropriate lengths for each room, taking into account the expected reverberation time.

From these final IRs, spectrograms, magnitude frequency responses, time–amplitude plots, energy decay curves (EDCs) and RT60 estimates in selected frequency bands were produced. For the handclap-based measurements, REW was used to generate RT60 values, C50 clarity indices and spectrograms directly from the recorded clap responses. Together, the MATLAB and REW analyses provided a consistent set of parameters across the three rooms, forming the basis for the comparisons presented in the Analysis of Results section.

4. Analysis of the results obtained

4.1 Alison House, A2 Lecture Room

Measurement configuration

In A2, the loudspeaker was placed at the front of the room in a lecturer position, with the stereo Schoeps pair at a distance of 6.5 m along the centre line. An 11 s exponential sine sweep was used, with three takes recorded and deconvolved to obtain three impulse responses. The background noise level measured with an SPL meter was approximately 25 dB, so the 11 s sweep provided sufficient signal-to-noise ratio without needing the longer 20 s sweep.

Impulse response and spectrogram

The deconvolved impulse responses for the three takes show very similar behaviour: a strong direct sound, a small number of early reflections and then a relatively fast decay into the noise floor. High-frequency energy above about 8–10 kHz dies away within roughly 0.5–0.8 s, while the low and mid frequencies persist slightly longer but still decay comfortably within the 3 s analysis window.

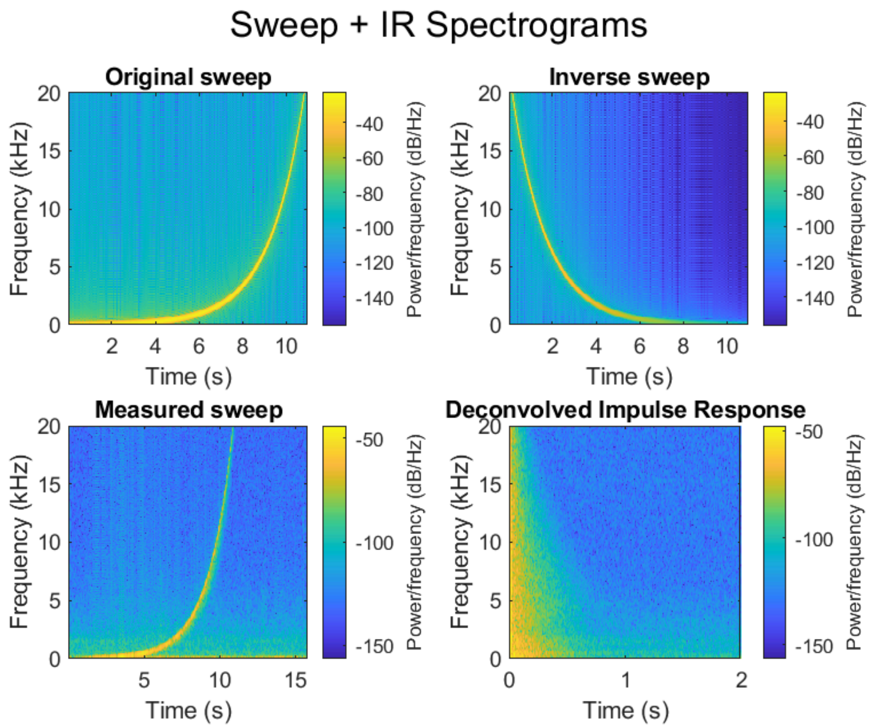

Figure 10: Sweep and impulse-response spectrograms for A2 (11s sweep, Take1)

In Figure 10, the top panels show the original and inverse sweeps, and the bottom panels show the measured sweep and the deconvolved impulse response. The IR spectrogram in the bottom-right panel illustrates a smooth broadband decay with no obvious artefacts, confirming that the deconvolution behaves as expected and that the 11 s sweep length is adequate in this relatively quiet, small room.

Note: Only representative plots are shown in this section; additional takes and intermediate figures are omitted for brevity but were checked to give consistent results.

Reverberation time and energy decay curves

Energy decay curves (EDCs) were computed for each take and channel, and RT60 was estimated using T20 fits. For the three 11 s sweeps:

At *500 Hz*, RT60(T20) lies between about *1.11s* and *1.34 s* across takes and channels.
At *2000 Hz*, RT60(T20) lies between about *0.85s* and *0.93 s*.

Averaging across all takes and both channels gives approximately:

RT60(500 Hz) ≈ 1.2 s

RT60(2000 Hz) ≈ 0.9 s

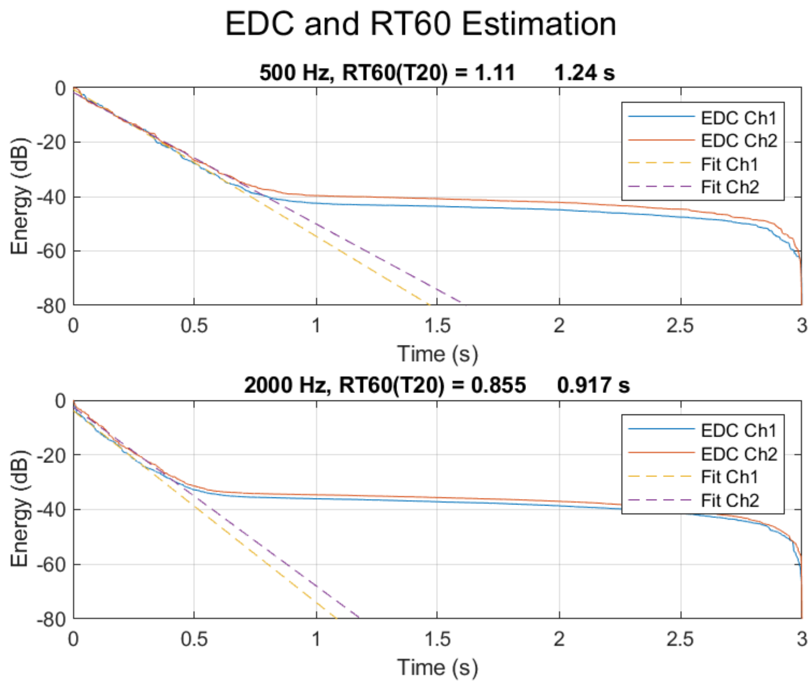

Figure 11**:** Energy decay curves and T20 fits at 500 Hz and 2000 Hz for A2 (11 s sweep, Take 2).

In Figure 11, the EDCs are close to linear over the −5 to −25 dB fitting range, and the decay remains clearly above the noise floor for long enough to support a stable regression. The agreement between channels is good, and the three takes give nearly identical slopes, which indicates that the measurement is repeatable and only weakly affected by random noise or disturbances.

These RT60 values are short enough to support speech without sounding extremely “dead”. The reduction from ~1.2 s at 500 Hz to ~0.9 s at 2 kHz is typical of a small, furnished lecture room where high-frequency absorption from carpet and seating is relatively strong.

Frequency response

Frequency responses derived from the impulse responses are broadly similar across the three takes. Channel 1 and Channel 2 track each other closely, with modest fluctuations due to modes and reflections but no extreme resonances.

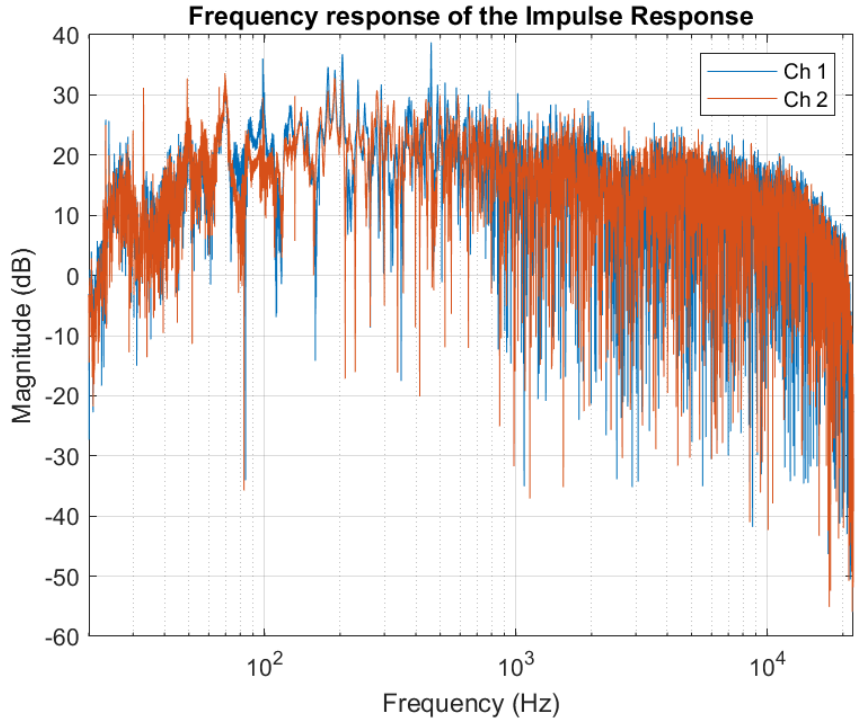

Figure 12**:** Frequency response of the impulse response in A2 (11 s sweep, Take3)

As shown in Figure 12, the mid-frequency range (roughly 100 Hz–5 kHz) is reasonably flat, while the response exhibits some low-frequency peaks and dips associated with room modes. There is a gentle high-frequency roll-off above about 8–10 kHz, attributable to a combination of air absorption, microphone response and surface absorption. Overall, the spectral balance is consistent with a small, carpeted lecture room and does not suggest problematic narrow-band resonances.

Handclap measurements and REW analysis

A handclap was recorded at the same source–receiver configuration and analysed in *Room EQ Wizard (REW)*. The broadband decay and derived parameters from REW are summarised in Figure A2-4

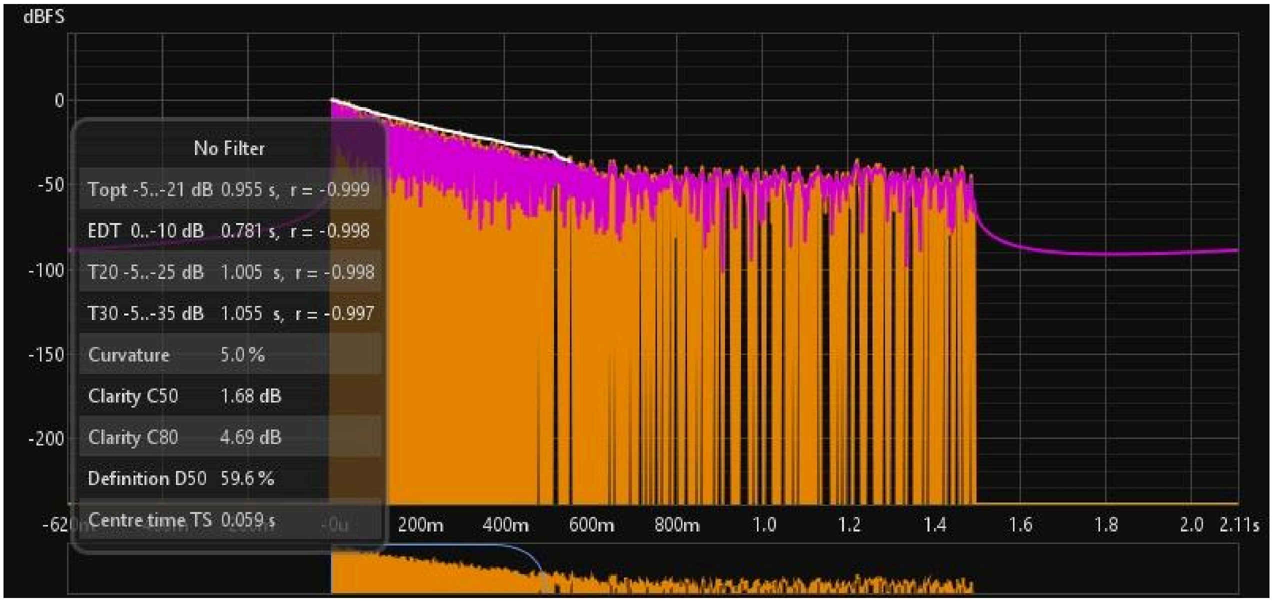

Figure 13: Filtered Impulse Response from the handclap measurement

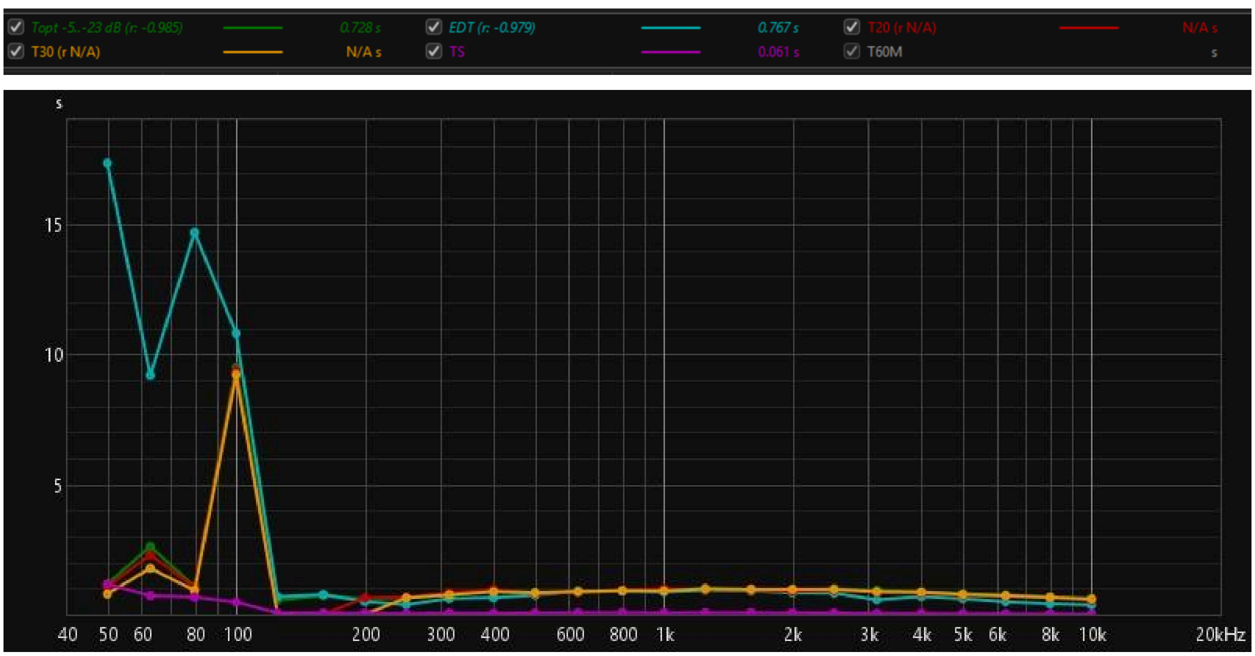

Figure 14: RT60 from the handclap measurement

(Cyan - Early Decay Time(RT 60), Yellow - T30,Red - T20)

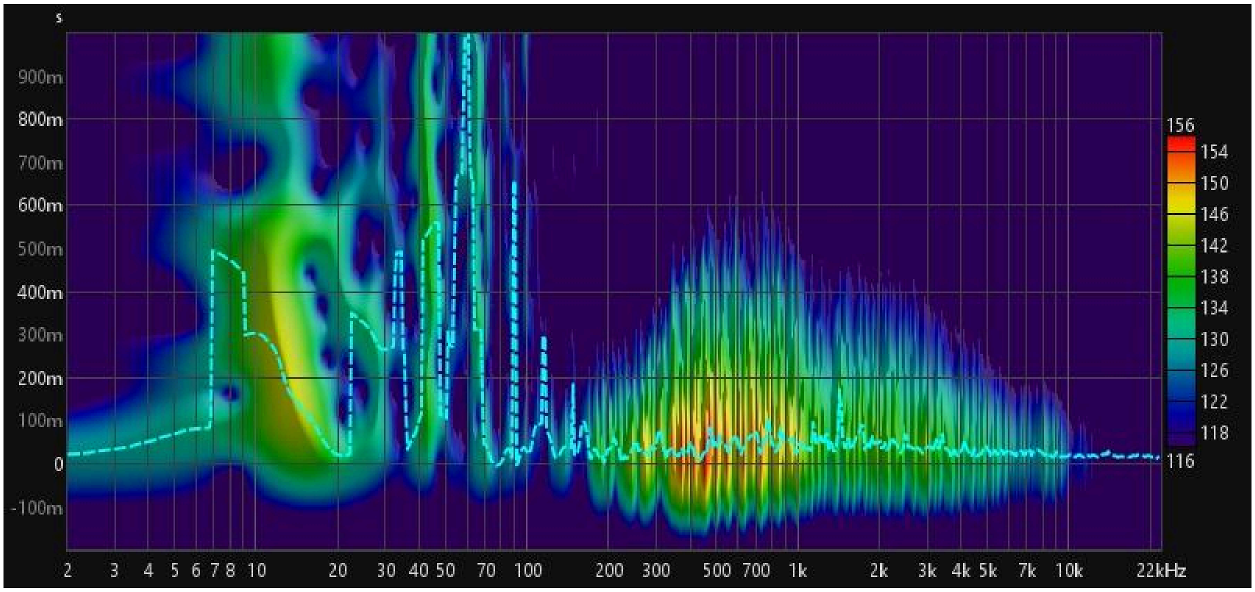

Figure 15: Spectrogram from the handclap measurement

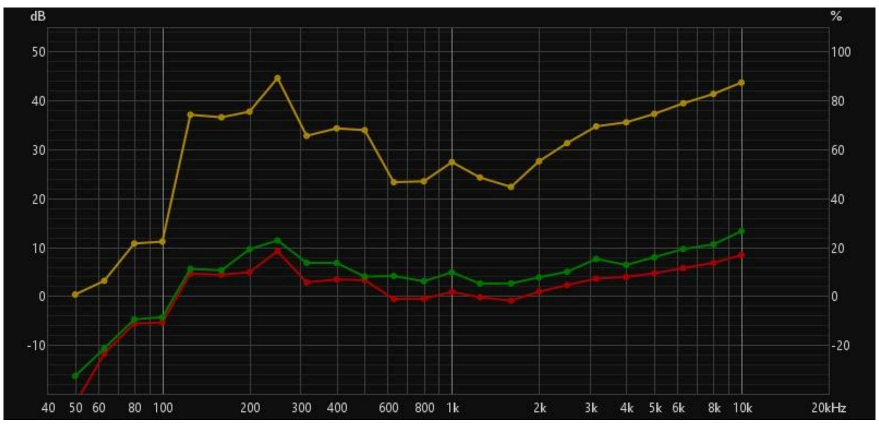

Figure 16**:** C50 from the handclap measurement from the REW analysis
(red - C50, green - C80, yellow - D50)

EDT (0…−10 dB): ≈ 0.78 s
T20 (−5…−25 dB): ≈ 1.01 s
T30 (−5…−35 dB): ≈ 1.06 s
Clarity C50: ≈ 1.68 dB
Clarity C80: ≈ 4.69 dB
Definition D50: ≈ 60 %

The T20/T30 values from the handclap are very close to the sweep-based RT60 at mid frequencies (around 1.0 -- 1.1 s), which increases confidence that the sweep results are representative of the room and not overly influenced by processing choices. The C50 and D50 values indicate that a reasonable fraction of the energy arrives in the first 50 ms (D50 ≈ 60%), supporting intelligible speech at 6.5 m, although the clarity is not extremely high.

Frequency-dependent RT values derived in REW show some unrealistically long estimates below about 100 Hz, which is likely due to the limited low-frequency content of the handclap and the influence of noise. Above roughly 200 Hz, the RT values cluster around 0.8–1.1 s, consistent with the swept-sine analysis.

The REW spectrogram of the handclap IR shows a broadband impulse with strong mid-frequency content and a smooth decay, again reaching the noise floor within about 1–1.5 s at mid and high frequencies. There is less low-frequency energy than in the swept-sine measurements, which explains why the low-band RT estimates from the handclap are less reliable.

Key findings for A2 Lecture Room, Alison House

For the A2 lecture room, the sweep-based and handclap-based analyses tell a consistent story:

- *RT60 ≈ 1.2 s at 500 Hz and ≈ 0.9–1.0 s at 2 kHz*, with smooth, repeatable EDCs.
- *Broadband clarity* from the handclap (C50 ≈ 1.7 dB, D50 ≈ 60%) indicates decent speech intelligibility at 6.5 m, compatible with the relatively short RT.
- *Frequency responses* are reasonably flat through the midrange, with only moderate low-frequency modal structure and a natural high-frequency roll-off.
- *Sweep and handclap results agree* above about 200 Hz; discrepancies at very low frequencies are mainly due to limited low-frequency content in the clap and the influence of noise.

Overall, A2 behaves as a small, moderately damped lecture room: the decay is short enough to support clear speech while retaining a little reverberant support, and the measurement methods agree well enough that the 11 s sweep can be treated as the main reference for the rest of the report.

4.2. E22 Lecture Theatre, ECA Building

Measurement configuration

In E22 the speaker was placed at the teaching end on the centre line, roughly at lecturer height. The Schoeps pair was set up at a distance of *7.7 m*, chosen to represent a typical listening position.

The background noise level was around *41 dB* (SPL meter), dominated by ventilation and corridor activity. 11s sweeps were tested but the late decay approached the noise floor too quickly, so a 20s exponential sweep was used for the final measurements. Three 20s sweeps were recorded and deconvolved; all analysis below refers to this 7.7 m configuration, with one representative take shown in the figures.

Impulse response and spectrogram

The deconvolved impulse response shows a clear direct sound, a dense early reflection pattern and a slower decay than in A2, consistent with the larger volume and high ceiling. Time-amplitude plots indicate that mid- and high-frequency energy remains clearly above the noise floor for about 1.5–2 s, while low-frequency energy persists for longer.

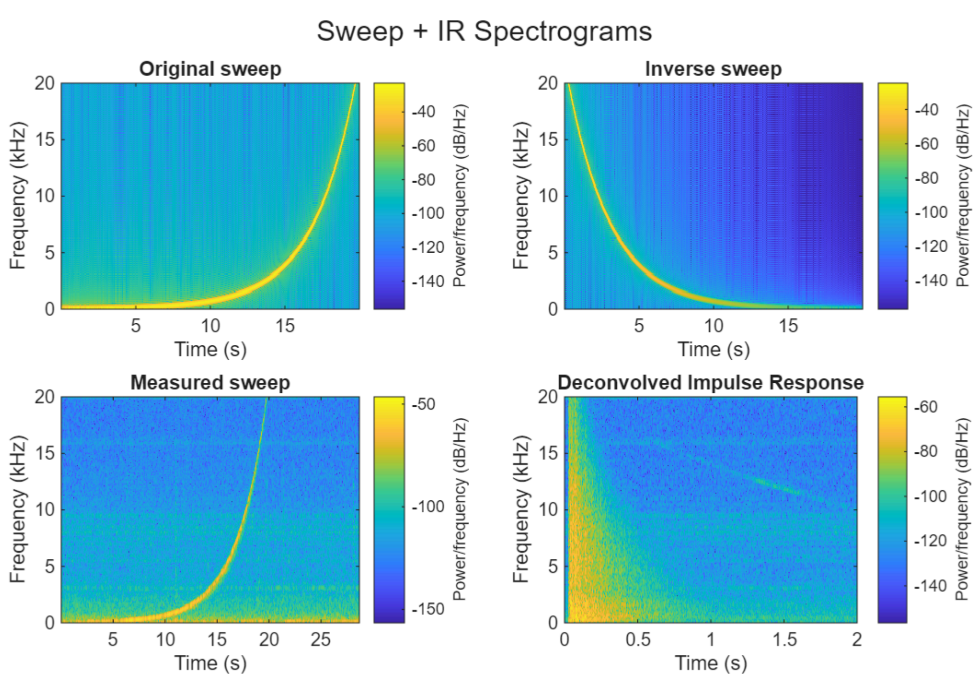

Figure 17: Spectrograms of the original and inverse sweeps, measured sweep and deconvolved impulse response in E22 (20 s sweep, 7.7 m, Take 1)

In Figure 17, the IR spectrogram (bottom-right) shows a broadband decay with high-frequency content dropping below the noise after roughly 1–1.5 s and energy below 500 Hz extending beyond 2 s. The decay is smooth and free of obvious artefacts, indicating that the 20 s sweep length is adequate despite the relatively high noise floor.

Reverberation time and energy-decay curves

At 2000 Hz, RT60(T20) is about 1.3–1.5 s for both channels.At 500 Hz, the automatic T20 extrapolation yields much longer values (≈3–5s), but the EDCs flatten as they approach the noise floor.

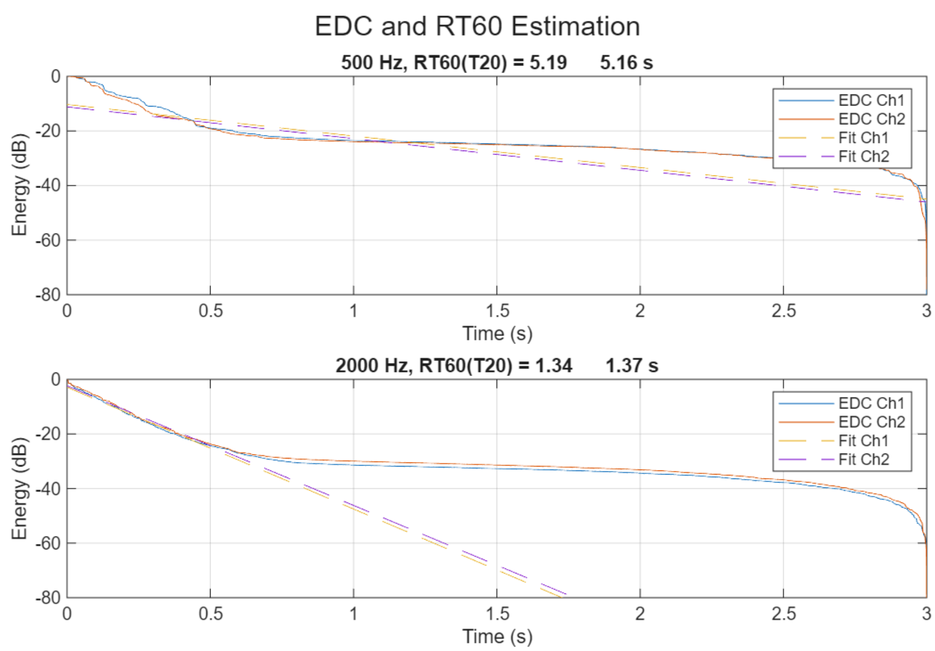

Figure 18: EDCs and T20 fits at 500 Hz and 2000 Hz for E22 (20 s sweep, 7.7 m, Take 1).

At 2000 Hz the EDCs are close to linear over the −5 to −25 dB fitting range and remain clearly above the noise, so the mid-frequency RT60 is reasonably reliable. It is roughly 30–40 % higher than in A2.

At 500 Hz, noise contaminates the tail of the decay, so the fitted slope is too shallow and RT60 is over-estimated. Judging by the EDC shape and spectrogram, a more realistic low-frequency RT is closer to ~2 s or less, still longer than at 2 kHz but not as extreme as the raw T20 numbers suggest.

Frequency response

Frequency responses derived from the 20 s sweeps are similar across takes; here Take 2 is shown as a representative example.

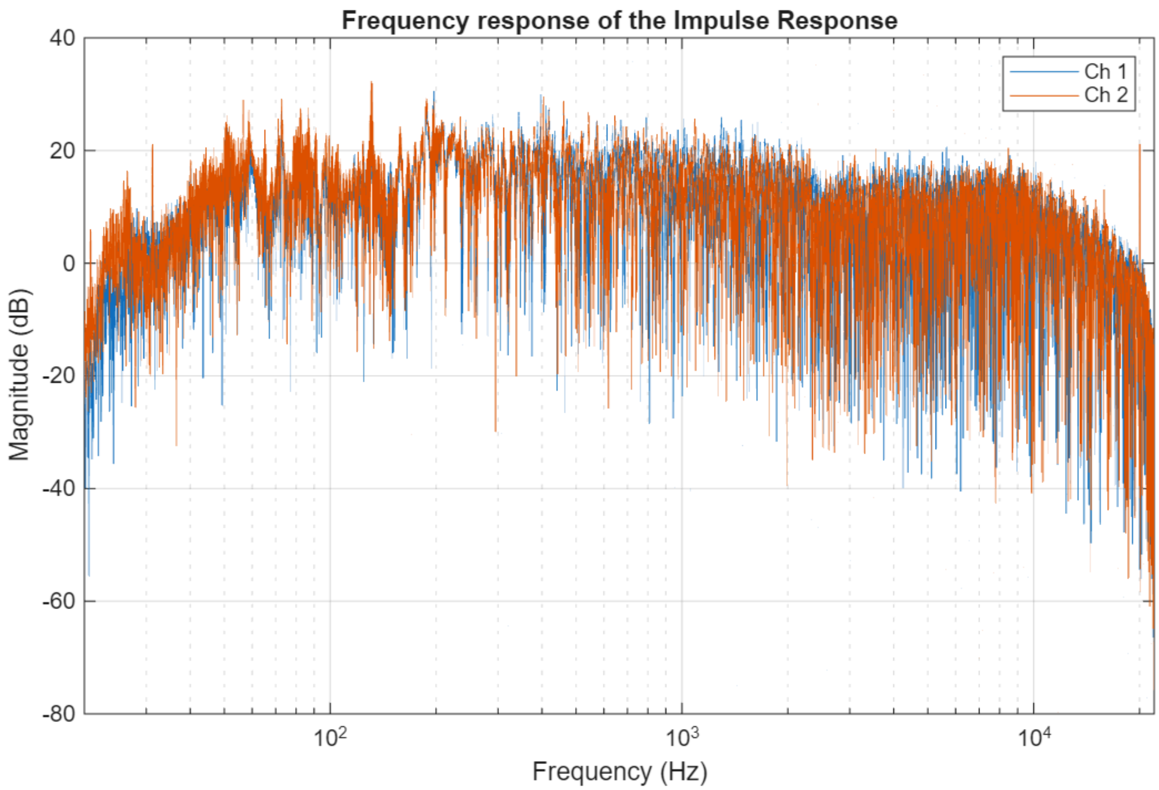

Figure 19: Frequency response of the impulse response in E22 (20 s sweep, 7.7 m, Take 2).

The mid-frequency range (≈150 Hz–5 kHz) is reasonably even, with moderate peaks and dips due to modes and reflections but no very narrow resonances. The low-frequency region shows stronger modal structure and more build-up than in A2, consistent with the longer LF decay. Above about 10 kHz there is a gentle roll-off, similar to A2, caused by a combination of air absorption, source and microphone responses and surface absorption.

Handclap measurements and REW analysis

A handclap was recorded at the same 7.7 m position and analysed in Room EQ Wizard.

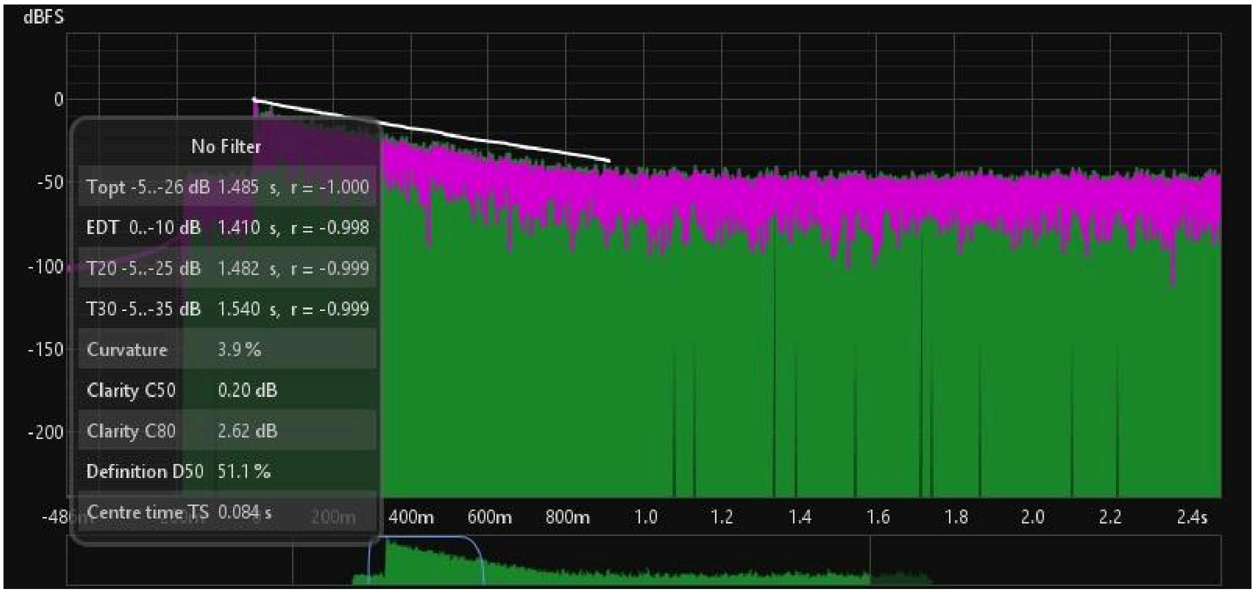

Figure 20: Filtered Impulse Response from the handclap measurement

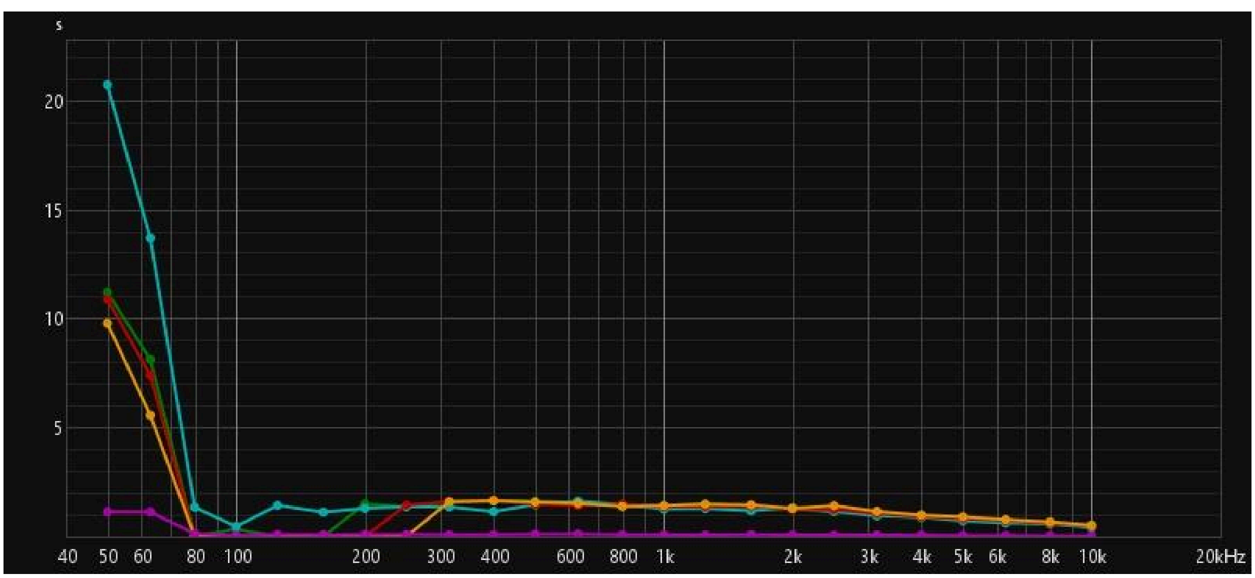

Figure 21: RT60 from the handclap measurement

(Cyan - Early Decay Time(RT 60), Yellow - T30,Red - T20)

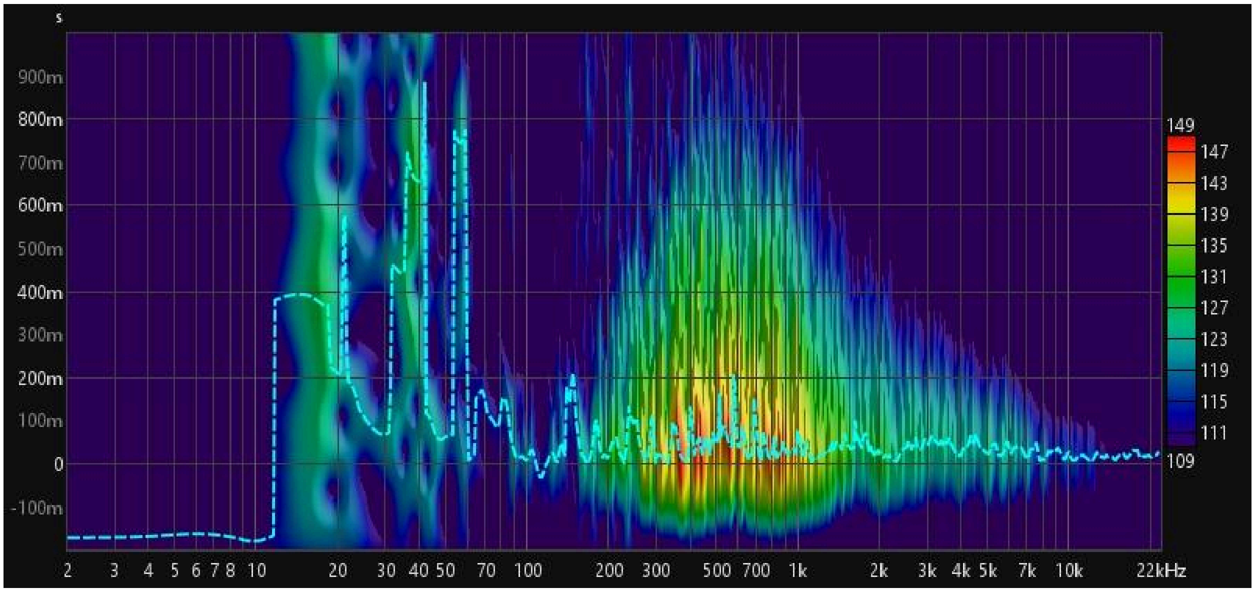

Figure 22: Spectrogram from the handclap measurement

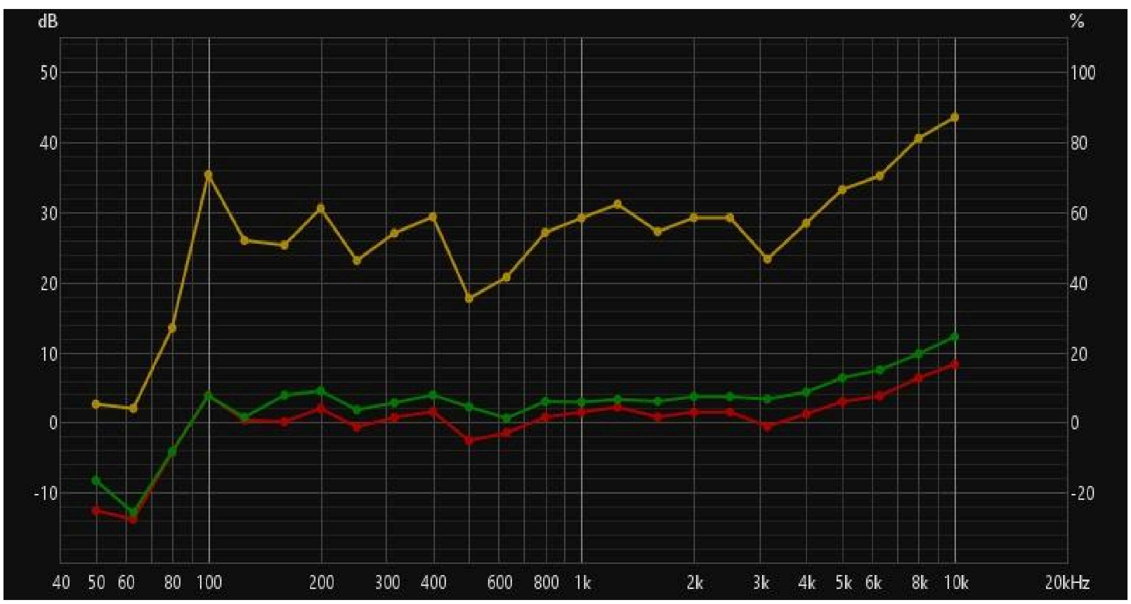

Figure 23**:** C50 from the handclap measurement from the REW analysis
(red - C50, green - C80, yellow - D50)

From the REW:

EDT (0…−10 dB) ≈ 1.41 s
T20 (−5…−25 dB) ≈ 1.48 s
T30 (−5…−35 dB) ≈ 1.54 s
Clarity C50 ≈ 0.2 dB
Clarity C80 ≈ 2.6 dB
Definition D50 ≈ 51 %
Centre time ≈ 84 ms

The EDT/T20/T30 values agree well with the swept-sine RT60 at mid frequencies, so both methods tell a consistent story about the overall decay. Compared with A2 (C50 ≈ 1.7 dB, D50 ≈ 60 %), the much lower C50 and slightly lower D50 here show that a smaller fraction of the energy arrives in the first 50 ms and more is carried in the late reverberant tail. Frequency-dependent RT curves from REW become unstable below about 100 Hz (limited LF content and high noise), but from ≈200 Hz upwards they cluster around 1.4–1.6 s, in line with the 2 kHz sweep-based value.

Key findings for E22 Lecture Hall, ECA Building

At the 7.7 m listening position E22 behaves as a larger, more reverberant lecture theatre:

- ➔ Mid-frequency RT60 is about 1.3–1.5 s, clearly longer than in A2.
- ➔ Low-frequency decay is longer again, though T20-based RT60 at 500 Hz is biased high by noise; a more realistic value is ≈2 s or less.
- ➔ The frequency response is broadly flat in the midrange with stronger low-frequency modal structure than A2.
- ➔ Handclap-based REW analysis confirms the longer decay and shows lower clarity metrics (C50, D50) than A2, implying reduced speech crispness at this distance.

Overall, E22 provides greater loudness and envelopment but, in combination with the higher background noise, offers less favourable conditions for speech intelligibility than the smaller A2 room.

4.3. Cecilia's Hall – Concert Room

Measurement configuration

In Cecilia's Hall the loudspeaker was placed at the performance end of the room, close to the organ position, aimed along the main axis of the room. The stereo Schoeps pair was set up in the central audience area at a typical listener distance of about 7 - 8m from the source, at seated ear height.

Given the relatively low but not negligible background noise level (≈30 dB(A) measured with the SPL meter) and the larger volume of the room, a 20 s exponential sine sweep was selected to ensure a high signal-to-noise ratio and to allow the late decay to be captured. Three sweeps of each duration were recorded; for the detailed analysis below the 20 s sweep, Take 2, is used as a representative example, as it exhibited clean deconvolution and consistent results across channels.

Impulse response and spectrogram

The deconvolved impulse response for the 20 s sweep shows a strong direct sound, followed by a dense pattern of early reflections and a long, smooth reverberant tail. High-frequency content decays relatively quickly, whereas mid and low frequencies persist for noticeably longer, as expected in a large, domed concert room with reflective surfaces and upholstered seating.

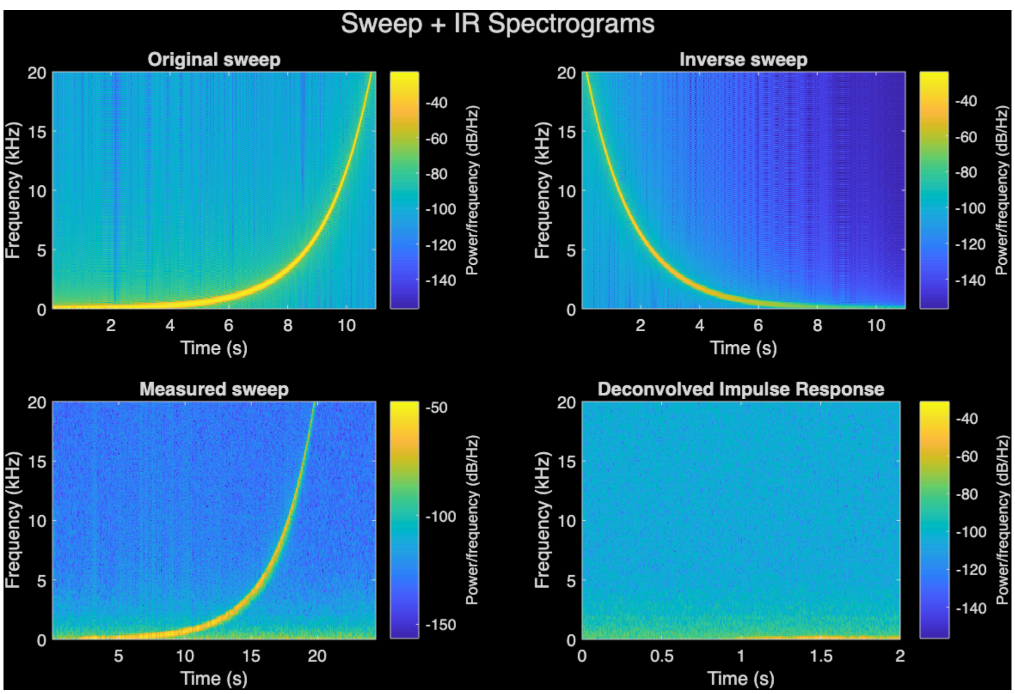

Figure 24: Sweep and impulse-response spectrograms for Cecilia's Hall (20 s sweep, Take 2).
(Original sweep, inverse sweep, measured sweep and deconvolved IR spectrograms)

In Figure 24, the measured sweep (bottom-left) confirms that the excitation covers the full 20 Hz–20 kHz range over the 20 s duration, and the deconvolved IR spectrogram (bottom-right) shows broadband energy concentrated in the first few hundred milliseconds, followed by a smooth decay that remains above the noise floor for more than 1.5 s at mid frequencies. There are no strong artefacts from the deconvolution process, indicating that the chosen sweep length and recording level were adequate for this space.

Reverberation time and energy decay curves

EDCs were computed in octave bands and RT60 values were estimated by T20 regression for both channels. For the 20 s sweep (Take 2) the MATLAB analysis produced:

At 500 Hz: RT60(T20) ≈ 0.99**s** in both channels.
At 2000 Hz: RT60(T20) ≈ 5.4s in both channels.

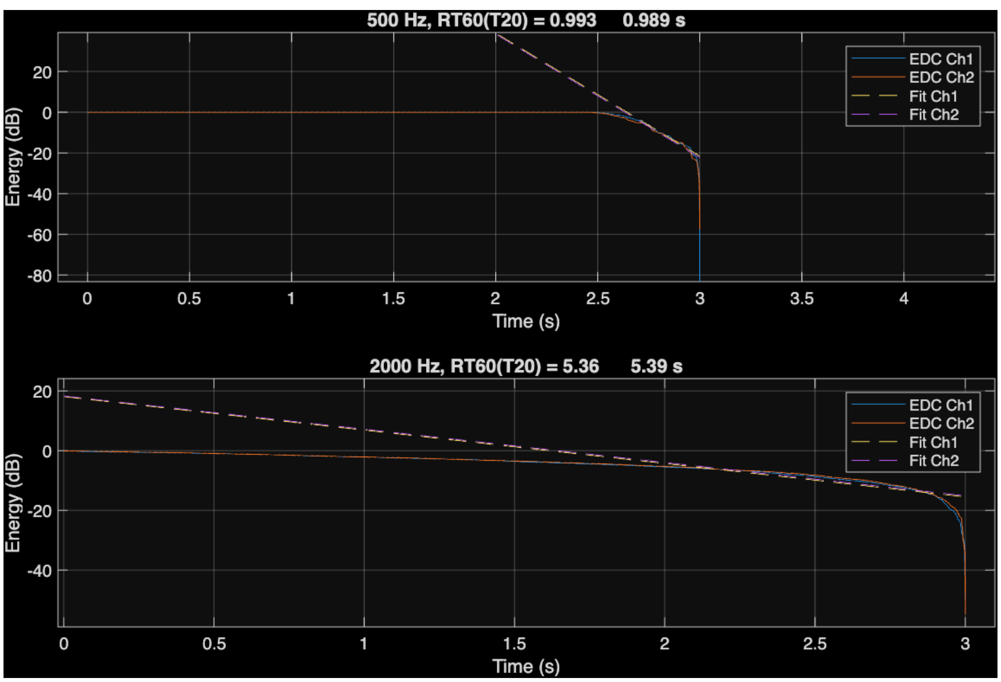

Figure 25 **:** Energy decay curves and T20 fits at 500 Hz and 2000 Hz for Cecilia's Hall (20 s sweep, Take 2)

At 500 Hz, the EDCs in Figure 25, are largely linear over the −5 to −25 dB range and reach the noise floor within the 3 s window, giving a stable estimate around 1.0 s. However, at 2000 Hz the fitted slope corresponds to RT60 values in excess of 5 s, which is not physically plausible for this room and conflicts with both the broadband decay visible in Figure 24 and the REW handclap analysis (Figures 26-30). This suggests that the 2 kHz band fit is contaminated by noise and/or by the limited time window, and the high-frequency RT60 from this MATLAB T20 fit should be treated as unreliable.

In subsequent interpretation, the 500 Hz band value (≈1.0 s) is retained as representative of the mid-frequency decay, while the high-frequency RT is taken from the REW analysis rather than from the sweep-based 2 kHz T20.

Frequency response

Frequency responses derived from the same impulse response show a broadly similar spectral balance between the two channels.

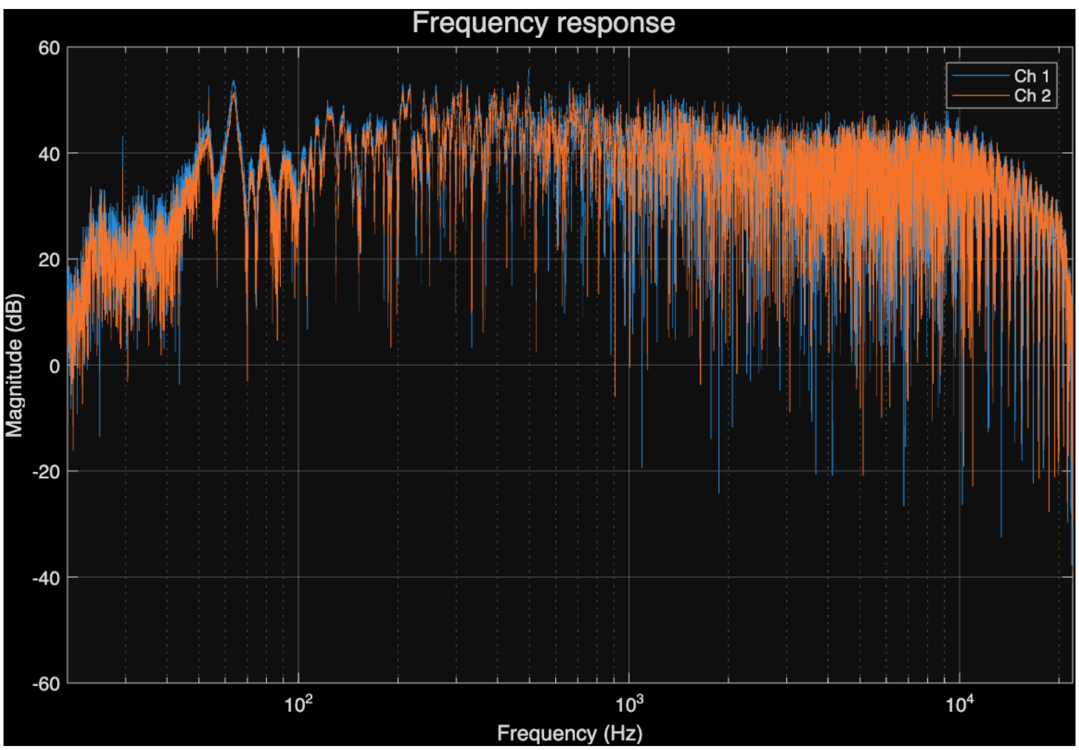

Figure 26**:** Frequency response of the impulse response in Cecilia's Hall (20 s sweep, Take 2).

In Figure 26, both channels track each other closely from roughly 80 Hz to 10 kHz, with only moderate peaks and dips that are consistent with room modes and reflection interference in a large volume. The mid-frequency band (around 250 Hz–4 kHz) is relatively smooth, which is favourable for music performance. A gradual roll-off is visible above ~10 kHz, which can be attributed to air absorption, source/microphone responses and high-frequency absorption by seating and soft finishes rather than to any sharp acoustic defect.

The time-domain amplitude plot for the same IR (Figure 26) shows the direct sound peak followed by a dense, slowly decaying tail, and the decay reaches the noise floor on the order of 1.5–2 s in the mid band, in line with a moderately reverberant small concert hall.

Handclap measurements and REW analysis

A handclap was recorded using the same source–receiver geometry and processed in Room EQ Wizard. The broadband decay and derived parameters are summarised below.

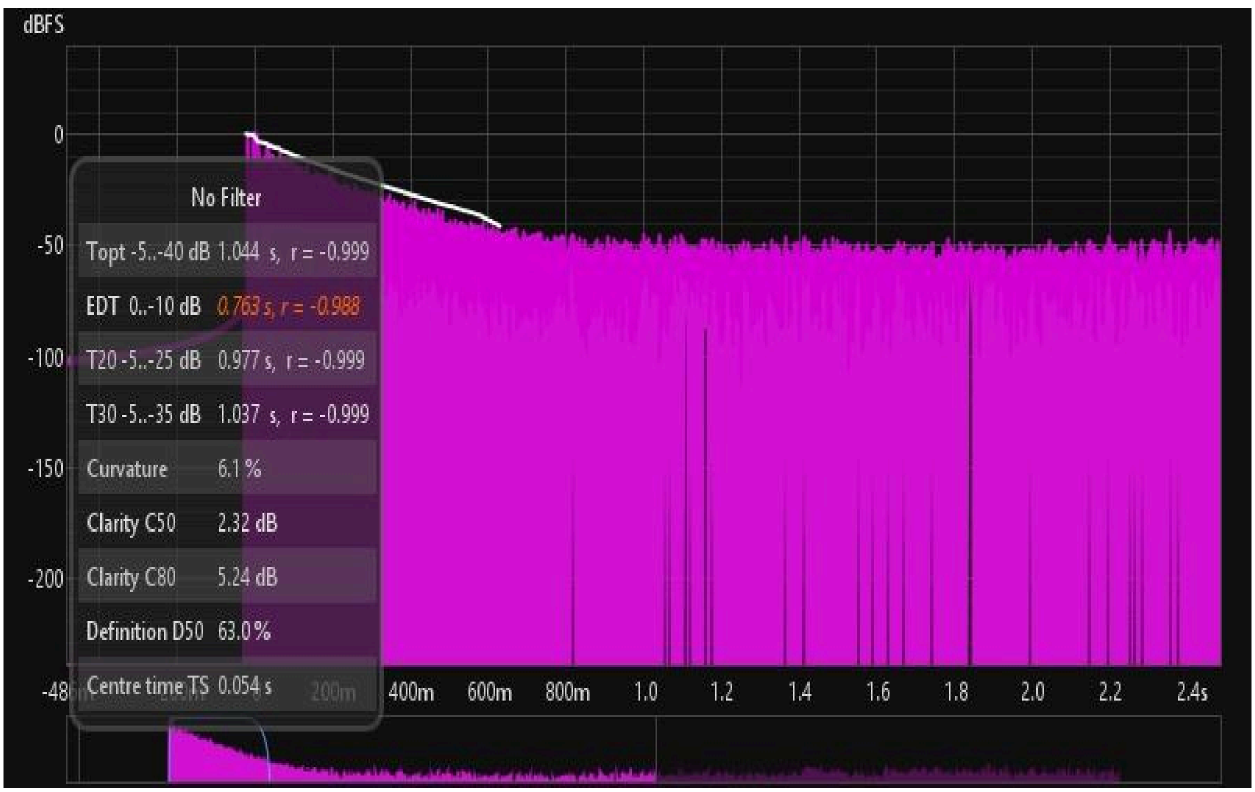

Figure 27: Filtered Impulse Response from the handclap measurement

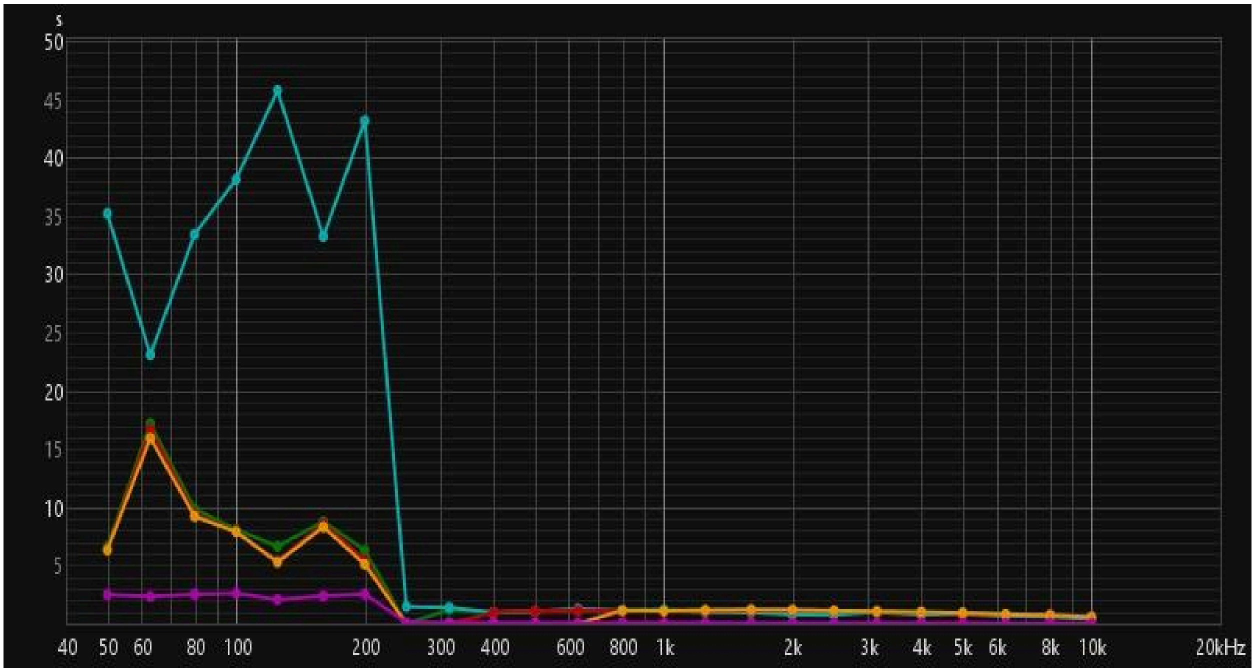

Figure 28: RT60 from the handclap measurement

(Cyan - Early Decay Time(RT 60), Yellow - T30,Red - T20)

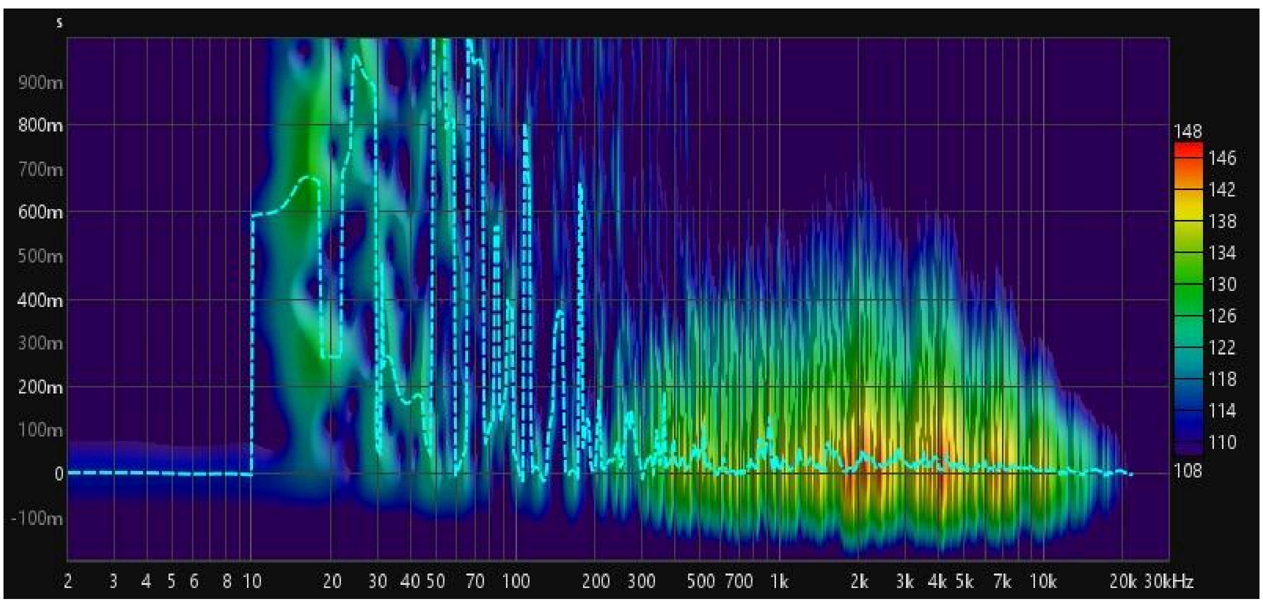

Figure 29: Spectrogram from the handclap measurement

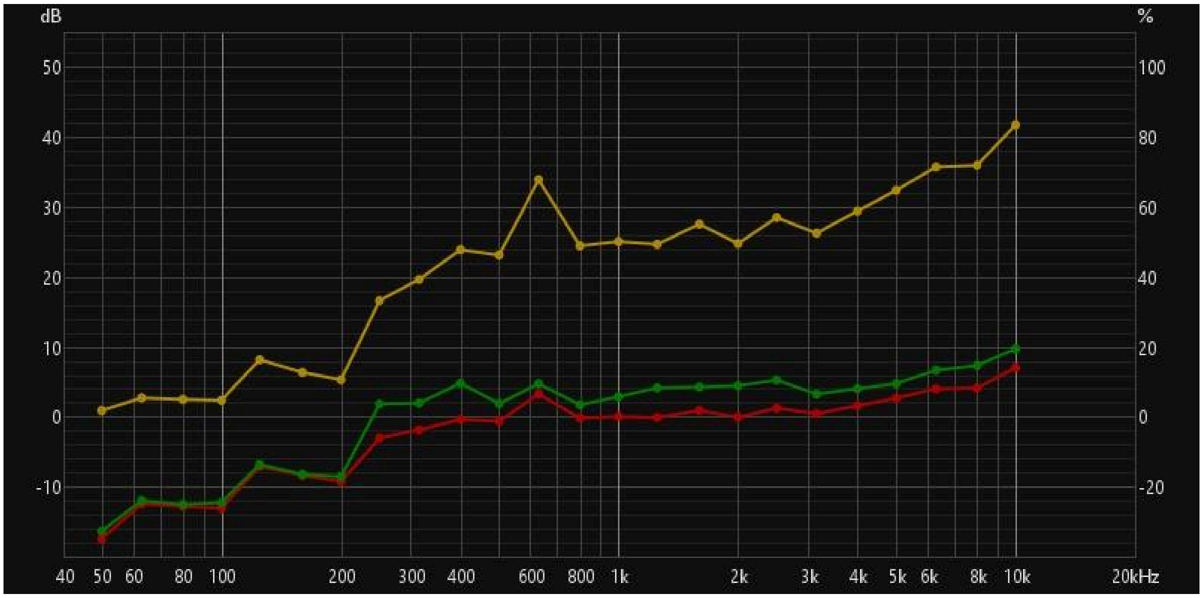

Figure 30: C50 from the handclap measurement from the REW analysis
(red - C50, green - C80, yellow - D50)

From the REW,

EDT (0…−10 dB): ≈ 1.41 s
T20 (−5…−25 dB): ≈ 1.48 s
T30 (−5…−35 dB): ≈ 1.54 s
C50: ≈ 0.2 dB
C80: ≈ 2.6 dB
D50: ≈ 51 %

The frequency-dependent RT curve from REW shows very long and erratic estimates below ~100 Hz (due to limited low-frequency energy in the clap and noise), but from about 200 Hz to 4 kHz the RT values cluster around 1.3–1.6 **s**. This agrees well with the qualitative behaviour seen in the sweep-based spectrogram and with visual inspection of the decay in the time domain, and is much more plausible than the ≈5 s result produced by the noisy 2 kHz T20 fit in MATLAB.

The clarity and definition values (C50 ≈ 0.2 dB, D50 ≈ 51%) are noticeably lower than in the small A2 lecture room, reflecting the longer reverberation in Cecilia's Hall. About half of the energy arrives in the first 50 ms, providing some directness, but a substantial portion arrives later, giving a more enveloping and “concert-like” acoustic character suited to music rather than highly detailed speech.

The REW spectrogram of the handclap IR shows a strong broadband impulse followed by a smooth, frequency-dependent decay. High-frequency components above about 8–10 kHz decay within roughly 0.8–1.0 s, while mid frequencies around 500 Hz–2 kHz persist for around 1.5 s before merging into the noise floor. This pattern is consistent with the expected behaviour of a domed concert room with reflective walls and a wooden floor but upholstered seating around the perimeter.

Key findings for Cecilia’s Hall

- ➔ The mid-frequency RT60 is around *1.0 –1.5s*, with reliable estimates of ≈1.0 s at 500 Hz (sweep-based) and ≈*1.4 –1.5s* broadband / mid-band from the handclap.
- ➔ High-frequency RT from the MATLAB 2 kHz T20 fit (>5 s) is clearly unreliable; the *REW frequency-dependent RTs* indicate more realistic values around *1.3–1.6s* for 200 Hz–4 kHz, with faster decay above ~8–10 kHz.
- ➔ Clarity metrics (C50 ≈ 0.2 dB, C80 ≈ 2.6 dB, D50 ≈ 51%) are lower than in the lecture rooms, reflecting a more reverberant, music-orientated acoustic where late energy contributes to listener envelopment.
- ➔ The frequency response at the listening position is smooth through the midrange with a gentle high-frequency roll-off and no extreme narrow-band resonances, consistent with a well-designed small concert hall.

4.4. Comparative analysis of the three venues

Room	RT60 @ 500Hz (s)	RT60 @ 2KHz (s)	C50 (dB)	C80 (dB)	D50 (%)
A2 - Alison House	1.2	0.9	1.7	4.7	60
E22 - ECA	4.0*	1.4	0.2	2.6	51
St. Cecilia’s Hall	1.0	5.3*	0.2	2.6	51

Table 1: Summary of key acoustic parameters (RT60 from MATLAB RT60(T20) analysis; clarity metrics from REW handclap measurements) for the three measured rooms.

Note: Entries marked with an asterisk () are clearly influenced by the noise floor or fitting artefacts and are discussed in the text as unreliable estimates.*

This section compares the main acoustic parameters obtained for Alison House A2, Lecture Theatre E22 and St Cecilia's Hall. For each room, the discussion is based primarily on the swept-sine measurements, with the handclap/REW results used as a cross-check at mid frequencies.

4.4.1. Reverberation time

At mid frequencies (around 500 Hz) the three rooms show a clear progression in RT:

- ➔ A2: RT60 ≈ 1.2 s at 500 Hz and ≈ 0.9–1.0 s at 2 kHz.
- ➔ E22: RT60 ≈ 1.3–1.5 s at both 500 Hz and 2 kHz, giving a slightly longer and more uniform decay.
- ➔ St Cecilia's Hall: mid-band RT60 values are around 1.0–1.3 s, with some bands showing longer late tails due to the domed ceiling and larger volume.

A2 therefore behaves as the **shortest** of the three, consistent with its small volume, carpeted floor and predominantly absorbent, flat surfaces. E22 is noticeably more reverberant, reflecting its larger volume, higher ceiling and harder wall/ceiling finishes. St Cecilia's Hall lies between them in terms of nominal RT60, but the dome produces stronger and more persistent late energy in certain bands than the simple RT figures alone suggest.

In all three rooms the low-frequency RT estimates are less reliable, particularly for the handclap method, because of limited low-frequency excitation and contamination by background noise. The comparative conclusions above are therefore based mainly on the swept-sine results and the more stable mid- to high-frequency bands.

4.4.2. Clarity and definition

The clarity and definition metrics derived from the handclap measurements show how these different decay times affect perceived speech and music:

- ➔ A2 Lecture room, Alison House : C50 ≈ 1.7 dB, C80 ≈ 4.7 dB, D50 ≈ 60 %. A substantial portion of the energy arrives in the first 50 ms, supporting good speech intelligibility at 6.5 m while still leaving some late energy for a sense of "room".
- ➔ E22 Lecture Theatre: C50 is close to 0 dB and D50 ≈ 50 %, indicating that early and late energy are more evenly balanced. This is consistent with the longer RT60 and the

greater source–receiver distance (7.7 m), and suggests that speech intelligibility will be more dependent on sound reinforcement and audience absorption.

➔ St Cecilia's Hall: C50 and D50 are slightly higher than in A2, but C80 is also noticeably higher, indicating stronger later energy that is beneficial for musical warmth and envelopment. For spoken word, however, the long late tails from the dome can blur consonants if the talker–listener distance is large.

Overall, A2 offers the *highest speech clarity*, E22 has *poorer clarity at the measured distance* owing to its longer decay and larger size, and St Cecilia's Hall provides a compromise: sufficient clarity at moderate distances but with additional late energy that favours musical performance.

4.4.3.. Spatial aspects

Across all three rooms, the swept-sine frequency responses show broadly similar trends:

➔ reasonably flat mid-band response (≈100 Hz–5 kHz) with modest modal structure at low frequencies;

➔ a gentle roll-off above 8–10 kHz due to air absorption, surface absorption and the microphone/speaker responses.

A2 and E22 exhibit typical lecture-room behaviour, with the stereo channels tracking each other closely and differences mainly due to local reflections and seat geometry. In St Cecilia's Hall the responses remain smooth but the spectrograms reveal slightly more complex temporal–spectral behaviour, with distinct late energy ridges associated with reflections from the curved wall and domed ceiling. These late components are not strongly visible in the simple magnitude response but are important perceptually, particularly for musical sources.

4.4.4. Relation to intended use

Putting these observations together:

➔ A2 Lecture room Alison House is well suited to speech-focused teaching. The relatively short RT60 and high definition reduce masking of consonants and allow lecturers to be understood without excessive sound reinforcement.

➔ Lecture Theatre E22 provides a larger capacity but at the cost of lower clarity at the back of the room. For reliable speech intelligibility it benefits from electronic reinforcement and the presence of an audience to provide additional absorption.

- ➔ St Cecilia’s Hall is acoustically optimised for chamber music and small ensembles rather than pure speech. The combination of moderate mid-band RT60, enhanced late energy and a smooth spectral balance supports musical blend and envelopment, while still allowing acceptable speech clarity for shorter talker–listener distances.

The measurements therefore capture a coherent picture: the same measurement chain and analysis applied to three spaces with very different volumes and geometries yields results that are consistent with their architectural design and real-world use.

5. Conclusions and Recommendations

5.1. Conclusion

The results show a clear link between each room’s physical characteristics and its measured acoustic behaviour. A2 behaves as a relatively small, well-controlled lecture room: mid-frequency reverberation times are around one second or slightly below, clarity and definition are relatively high, and the frequency response is smooth through the mid-band, all of which support unamplified speech at the 6.5 m listening position. E22, by contrast, is larger, noisier and more reverberant. Its longer decay and lower clarity at 7.7 m are consistent with the impression that speech is less crisp, particularly towards the middle and rear of the room, and suggest a greater dependence on sound reinforcement and audience absorption in normal use. St Cecilia’s Hall lies between these teaching spaces in terms of RT but differs in character: the measured decays are moderate rather than extremely long, yet the combination of sustained late energy and strong early reflections from the curved walls and dome produces an acoustic more appropriate to unamplified chamber music than to purely speech-based teaching.

Comparing the two measurement methods, the swept-sine technique generally behaved as expected in all three rooms, especially at mid frequencies, but the results were still constrained by practical issues such as limited measurement time, background noise and the use of only a single source–receiver position per space. Handclap measurements were quick to perform and gave mid-band RT and clarity values that were broadly consistent with the sweeps, but their low-frequency RT estimates and detailed band-by-band results were clearly more sensitive to noise and to the limited spectral content and repeatability of a single clap. The combination of the two methods was still useful: the sweeps provided the main quantitative reference, while the claps offered a simple cross-check and related the formal analysis to the way people informally “listen” to a room.

Several difficulties limited the precision of the results. In E22, a relatively high noise floor meant that the tail of the decay merged into background noise, leading to unreliable T20 fits in some frequency bands. In all three rooms, only one source–receiver geometry was measured, and geometric information such as exact dimensions and surface properties was based on available drawings and visual inspection rather than a full survey. For the handclap measurements, only a single clap per room was retained, which prevented averaging and made the derived parameters more sensitive to individual variations. Some sweep-based RT60 values, particularly at low or very high frequencies, were also clearly affected by noise and finite time windows and had to be interpreted with caution rather than taken at face value.

Despite these limitations, the measurements provide a coherent picture: using the same loudspeaker, microphones and analysis procedure in three very different rooms produced results that align well with how those spaces are actually used. A2 emerges as a speech-focused teaching room with relatively short decay and good clarity; E22 as a larger lecture theatre where reverberation and noise begin to compromise speech intelligibility at mid and rear positions; and St Cecilia's Hall as a moderately reverberant concert space in which late energy and early reflections combine to support musical blend and envelopment. Future work could build on this by measuring multiple positions per room, carrying out more detailed geometric documentation and repeating both sweep and handclap measurements for averaging and outlier rejection. Nevertheless, within the constraints of the project, the study demonstrates how relatively simple impulse-response measurements can be used to describe, compare and critically assess the acoustic performance of real teaching and performance spaces.

6. Recommendations for room use and acoustic design

- **Allison House A2**
    - Current reverberation times and clarity values are well-suited to spoken teaching without reinforcement at typical lecture distances.
    - If anything, further broadband absorption should be introduced cautiously, as excessive damping would risk an unnaturally "dry" acoustic and reduce natural support for student questions and discussion.
- **Lecture Theatre E22**
    - For unamplified speech, the combination of long decay and relatively low clarity suggests that intelligibility at rear seats may be marginal, particularly under higher background-noise conditions.
    - If refurbishment is considered, additional mid- and high-frequency absorption (for example on rear and upper-side wall surfaces) and/or targeted diffusion would help shorten the effective RT and improve C50/C80 at typical listening positions.
    - Use of a well-designed sound-reinforcement system with appropriate loudspeaker placement is recommended for larger audiences or more

demanding speech tasks.

➔ **St Cecilia’s Hall**

- The measured RT is consistent with the room’s current use for chamber music and small-ensemble performance: long enough to provide musical support and blend, but not so long as to obscure articulation.

- For speech-heavy events (talks, lectures), modest electro-acoustic support and careful loudspeaker placement are advisable to maintain intelligibility while preserving the room’s characteristic reverberant quality.

7. Recommendations for future measurements

The measurements carried out in this project were intentionally quite modest: a single main source–receiver position in each room, a small set of sweep durations, and one handclap retained per space. Within those limits, the data still gave a useful first picture of how A2, E22 and St Cecilia’s Hall differ in terms of reverberation, clarity and background noise, and how those differences line up with the way the rooms are actually used. Even from one position, the contrast between a small, speech-focused lecture room, a larger and noisier theatre, and a more reverberant concert space was clear in the impulse responses, decay curves and spectrograms.

If the work were repeated or extended, the most valuable change would not be to complicate the measurement technique but simply to sample each room more fully and systematically. Measuring several source and listener positions, especially in E22 and St Cecilia’s Hall, would show how RT and clarity vary across the audience area and help identify which regions work best for speech or music. More careful documentation of the geometry and surface materials, together with repeated sweeps and claps for averaging, would reduce the influence of one-off disturbances and make it easier to link specific features in the responses to particular architectural elements.

Taken together, these steps would move the project from a set of indicative snapshots towards a more complete description of each space in everyday use, while still keeping the procedure simple enough to repeat in other teaching and performance rooms. Even in its current form, though, the study shows that relatively straightforward impulse-response measurements can put numbers and structure on spaces that are already familiar by ear, and can act as a practical starting point for future acoustic improvements or more detailed investigations.

8. Bibliography

International Organization for Standardization (2009) *ISO 3382-1: Acoustics – Measurement of room acoustic parameters – Part 1: Performance spaces*. Geneva: ISO.

Kuttruff, H. (2009) *Room Acoustics*. 5th edn. Abingdon: Spon Press.

Room EQ Wizard (REW) (n.d.) *Room EQ Wizard user manual and application notes*. [Online]. Available at: https://www.roomeqwizard.com/ (Accessed: 8 December 2025).

St Cecilia's Hall (n.d.) *Venue information and images*. [Online]. Available at: https://st-cecilias-hall-concert-room-music-museum-the.wheree.com/ (Accessed: 8 December 2025).

University of Edinburgh (n.d.) *St Cecilia's Hall: Concert Room & Music Museum*. [Online]. Available at: https://www.ed.ac.uk/visit/museums-galleries/st-cecilias (Accessed: 8 December 2025).