Objective assessment of concert hall acoustics

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Objective measures for concert hall acoustics

• Can be used by people with NO knowledge of subjective issues!

• Except for reverberation time, average values for a hall need to be treated carefully, especially in the case of total level G.

• Are used (inappropriately?) for spaces other than those for unamplified music
### Recommended ranges for objective measures for concert halls (at mid-frequencies)

<table>
<thead>
<tr>
<th>Measure</th>
<th>Acceptable range</th>
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<tbody>
<tr>
<td>Reverberation time (RT)</td>
<td>$1.8 \leq RT \leq 2.2$ seconds</td>
</tr>
<tr>
<td>Early Decay time (EDT)</td>
<td>$1.8 \leq EDT \leq 2.2$ seconds</td>
</tr>
<tr>
<td>Early-to-late sound index ($C_{80}$)</td>
<td>$-2 \leq C_{80} \leq +2$ dB</td>
</tr>
<tr>
<td>Early lateral energy fraction (LF)</td>
<td>$0.1 \leq LF \leq 0.35$</td>
</tr>
<tr>
<td>Total relative sound level (G)</td>
<td>$G &gt; 0$ dB</td>
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</table>
Assessment relative to revised theory of sound level

Revised theory is based on the observation that total sound level in concert auditoria does not behave according to traditional theory. This behaviour is also found in a fully diffuse space.

![Diagram showing the behaviour of sound level G in a room with different reflected sound components.]

- **Direct**
- **Traditional reflected sound**
- **Revised reflected sound**

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**Behaviour of sound level G in a room**
Sound level behaviour in a typical large concert hall

Graph showing the relationship between source-receiver distance (m) and mid-frequency total sound level (dB). The graph includes both experimental data points and theoretical predictions.
Revised equation for reflected sound level

Traditional theory

\[ L_{\text{refl}} = 10 \cdot \log \left( \frac{31200 \cdot T}{V} \right) - \frac{0.174 \cdot r}{T} \text{ dB} \]

‘Slope’

Note, slope is an inverse function of reverberation time
Assumed integrated decays with revised theory

Measured vs. revised theoretical sound level
Mid-frequency values without overhung locations
Subdivision of the total sound

If \( e \) is the early energy and \( l \) is the late component, then

\[
G = 10 \cdot \log (e + l) \quad \text{and} \quad C_{80} = 10 \cdot \log (e/l)
\]

So from measurements of \( G \) and \( C_{80} \), the early and late level can be derived (\( E = 10 \cdot \log e \) and \( L = 10 \cdot \log l \))

Revised theory can also be used to predict the early and late components

Note: measurements reported below have the source on centre line, 3 m from front stage front, so no stage floor reflections

The ‘new’ analysis technique involves comparison of the early, late, total and early-to-late index with revised theory predictions
Proposed graphs for temporal energy analysis

- Early (10.log e)

- Late (10.log l)

- Total (10.log (e + l))

- C₈₀ (10.log e/l)
Objective behaviour influenced by auditorium geometry

Early (10.\log e)

Late (10.\log l)

Total (10.\log (e + l))

C_{80} (10.\log e/l)

Subjective quantities
Determinants of objective behaviour

Early sound – direct + early reflections

Late sound – access to reverberant sound

Note that RT and volume are included in the prediction

For assessment of G and $C_{80}$, correction for RT change is necessary when measurements have been made in an unoccupied concert hall
Sound behaviour under balcony overhangs

Major effect is on late sound

Overhang effect is linked to vertical angle of view, $\theta$
Objective behaviour in the Festival Hall follows revised theory fairly well except for the late sound at seats below the balcony overhang.

Royal Festival Hall, London (unoccupied, 1982)
Colston Hall, Bristol (unoccupied, 1982)

Major effect on late sound caused by balcony overhang subdividing the room vertically

Very wide range of $C_{80}$
Barbican Concert Hall, London (unoccupied, 1984)
Barbican Concert Hall, London (unoccupied, 1984)

Low early sound levels result in quiet sound and poor clarity in remote seats.
Fairfield Hall, Croydon ('occupied', 1982)

Early

Source-receiver distance (m)

Late

Source-receiver distance (m)

Total

Source-receiver distance (m)

C₈₀, early-to-late

Source-receiver distance (m)
Fairfield Hall, Croydon (‘occupied’, 1982)

At remote seats, low early and low late sound levels result in quiet sound towards the rear of the hall.
CONCLUSIONS

This analysis provides valuable insights into the interplay between geometrical design of concert halls and the acoustic consequences. Each concert hall has its story to tell.

Temporal energy analysis offers insights into the following:

- Overall geometrical design
- Balcony design
- Causes of high or low sound levels and objective clarity, C80
- Uniformity of response
- Comparison with average behaviour for volume and RT

Beware: agreement with revised theory is not necessarily the optimum
Temporal Energy Distribution Analysis

TEDIA ?  (tedium)

or

TEDI Analysis