REVERBERATION TIME IN ARCHITECTURAL ACOUSTICS
Revision A

By Tom Irvine
Email: tomirvine@aol.com

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Introduction
Reverberation is the echo effect which occurs in a room due to sound reflection.

Measurement
Reverberation time is measured by exciting a room with an impulse source. The response is measured by a microphone. The time required for the sound pressure level to decay by 60 dB is taken as the reverberation time, designated RT60. Extrapolation can be used if a full 60 dB decay cannot be measured.

Furthermore, the sound pressure is typically bandpass filtered in terms of octave bands. The reverberation time for each band is then calculated.

Design Criteria
A moderate amount of reverberation enhances both symphony music and speech.

A solemn, slow organ melody is enhanced by long reverberation. Quick rhythmic music is better served by a shorter reverberation time.

In general, music needs a greater amount of reverberation time than speech.

Excessive reverberation time can make speech unintelligible. Specifically, reverberation can mask “lower level consonants.”

Churches and other auditoriums must often accommodate both speech and music. Thus, some compromise is needed.

A design guideline taken from Reference 1 is given in Figure 1. This guideline is a “rule-of-thumb” since sound quality is subjective.
Figure 1.

ACCEPTABLE REVERBERATION TIMES AT 500 Hz
Sabine Equation

Sabine developed an equation for the RT60 reverberation time, as given in Reference 2. Note that this equation assumes the medium is air with a speed of sound equal to 343 m/sec, or 1125 feet/sec.

The English equation is

\[
RT60 = 0.049 \frac{\text{sec}}{\text{ft}^2} \left[ \frac{V}{A} \right]
\]  

(1)

where

- \( V \) = volume of room, cubic feet
- \( A \) = total sound absorption, English sabins, square feet

The equivalent metric equation is

\[
RT60 = 0.161 \frac{\text{sec}}{\text{m}^2} \left[ \frac{V}{A} \right]
\]  

(2)

where

- \( V \) = volume of room, cubic meters
- \( A \) = total sound absorption, metric sabins, square meters

The average Sabine absorption coefficient \( \bar{a} \) is

\[
\bar{a} = \frac{A}{S}
\]  

(3)

where \( S \) is the surface area of the room.

The total sound absorption is the sum of the absorption of individual surfaces.

\[
A = \sum_{i} S_i a_i
\]  

(4)

where \( a_i \) is the Sabine absorption coefficient of the \( i \)th surface.

Note that the absorption coefficients vary with frequency. The reverberation time for representative frequencies must be specified. These frequencies must cover the entire domain that is important to speech and music. The typical frequencies are 125, 250, 500, 1000, 2000, and 4000 Hz.
Typical absorption coefficients are shown in Table 1, as taken from Reference 3.

<table>
<thead>
<tr>
<th>Material</th>
<th>125 Hz</th>
<th>250 Hz</th>
<th>500 Hz</th>
<th>1000 Hz</th>
<th>2000 Hz</th>
<th>4000 Hz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brick, unglazed</td>
<td>0.03</td>
<td>0.03</td>
<td>0.03</td>
<td>0.04</td>
<td>0.05</td>
<td>0.07</td>
</tr>
<tr>
<td>Carpet, 1/8 inch pile height</td>
<td>0.05</td>
<td>0.05</td>
<td>0.10</td>
<td>0.20</td>
<td>0.30</td>
<td>0.40</td>
</tr>
<tr>
<td>Wood Floor</td>
<td>0.15</td>
<td>0.11</td>
<td>0.10</td>
<td>0.07</td>
<td>0.06</td>
<td>0.07</td>
</tr>
</tbody>
</table>

Note that audiences seated on upholstered seats yield much higher absorption coefficients as shown in Table 2. Ranges are given due to the variability in upholstery type, spacing of seats, etc.

<table>
<thead>
<tr>
<th>Audience seated in Upholstered Seats</th>
<th>125 Hz</th>
<th>250 Hz</th>
<th>500 Hz</th>
<th>1000 Hz</th>
<th>2000 Hz</th>
<th>4000 Hz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Audience seated in Upholstered Seats</td>
<td>2.5 - 4.0</td>
<td>3.5 - 5.0</td>
<td>4.0 - 5.5</td>
<td>4.5 - 6.5</td>
<td>5.0 - 7.0</td>
<td>4.5 - 7.0</td>
</tr>
</tbody>
</table>

Example

Calculate the total sound absorption and reverberation time at 500 Hz for an auditorium with dimensions:

- Length = 20 m
- Width = 10 m
- Height = 18 m

Volume = 3600 cubic meters

The materials and absorption parameters are shown in Table 3.
Table 3. Sound Absorption Calculation for Auditorium

<table>
<thead>
<tr>
<th>Material</th>
<th>Area Sq meters</th>
<th>Absorption Coefficient</th>
<th>Sabins, Sq meters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gypsum Board Walls and Ceiling</td>
<td>1280</td>
<td>0.05</td>
<td>62</td>
</tr>
<tr>
<td>Audience seated in Upholstered Seats</td>
<td>120</td>
<td>4.0</td>
<td>480</td>
</tr>
<tr>
<td>Carpet Floor</td>
<td>200</td>
<td>0.10</td>
<td>20</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td>562</td>
</tr>
</tbody>
</table>

The reverberation time at 500 Hz is

\[
RT60 = \left[ \frac{0.161 \text{ sec}}{\text{m}} \right] \left[ \frac{3600 \text{ m}^3}{562 \text{ m}^2} \right] = 1.03 \text{ seconds at 500 Hz}
\]

This value is at the lower limit for speech, per the guideline in Figure 1.

References