Prediction of Reverberation Times

As early as the 1920's, it has been shown (Sabine, 1927) that reverberation times provide a good metric of large room acoustics. In turn, reverberation characteristics affect intelligibility of speech (Steeneken & Houtgast, 1980), clarity of speech performances (Anhert & Schmidt, 1980) and music performances (Abdel-Alim, 1973).

In iRoom, reverberation times are estimated using a range of statistical and empirical equations, all of which are predicated on diffuse-field theory. The following section describes prediction models used by iRoom.

The first known RT[1] equation was an outcome of a five-year empirical study conducted by Wallace C. Sabine, and is given by (Beranek, 1992, p. 2)

$$T_{60} = 0.16\frac{V}{A} \tag{2.9}$$

Where the total absorption at room boundaries (A) is represented by a summation of the surface areas multiplied by their respective absorption coefficients, and is given by

$$A = \sum_i S_i \alpha_i \tag{2.10}$$

Where S_i is the area of the i^{th} surface and α_i is the absorption coefficient of the i^{th} surface.

The empirical coefficient 0.16 can be recalculated in function of velocity of sound in air. Rearranging Eq 4.13 accordingly and accounting for air absorption allows a more accurate formula (Cox & D'Antonio, 2004, p. 9):

$$T_{60} = \frac{55.3V}{cA + 4mV} \tag{2.11}$$

Further study by Eyring (1930) suggested that these formulae are only accurate in case of highly reverberant rooms. Relying on the mean free paths between reflections in a diffuse field, a revised theory was established resulting in a modified equation (Neubauer & Kostek, 2004). Often referred to as the Eyring Equation, it is given by

$$T_{60} = \frac{55.3V}{-cS \cdot \ln(1 - \bar{\alpha})} \tag{2.12}$$

Where the area-weighted average absorption coefficient is given by

$$\bar{\alpha} = \frac{1}{S}\sum_{i=1}^{N} S_i \alpha_i \tag{2.13}$$

Different methods for averaging absorption coefficients were proposed by Millington (1932) and Sette (1933), resulting in a modified equation given by

$$T_{60} = \frac{55.3V}{-c\sum_i S_i \ln(1 - \alpha_i)} \tag{2.14}$$

Reverberation Time [1]

Unlike prior models, Fitzroy (1959) takes into consideration not only the statistical absorption properties of the room, but also its geometric sound field. An estimation of the reverberation time is derived from an analysis of individual oscillations of sound energy between the three discrete axes of a room – vertical, longitudinal and transverse (Czyzewski & Kostek, 1999, pp. 116-117). Fitzroy's equation is given by

$$T_{60} = \frac{55.3V}{cS^2}\left[\frac{-S_x}{ln(1-\alpha_x)} + \frac{-S_y}{ln(1-\alpha_y)} + \frac{-S_z}{ln(1-\alpha_z)}\right] \qquad (2.15)$$

Where S_x, S_y, S_z are the total surface areas of two opposite boundaries (x,y,z) respectively, and $\alpha_x, \alpha_y, \alpha_z$ are the average absorption coefficients of each pair of opposite boundaries.

Arau (1988) assumes a hyperbolic reverberation decay process. The contribution of the initial energy decay and the following linear periods of reverberation in each axis of propagation are considered in respect to the mean absorption of each set of two parallel surfaces, resulting in an equation that performs well in cases of asymmetric distribution of absorption (Neubauer & Kostek, 2004). Arau's model is given by

$$T_{60} = \left[\frac{0.16V}{-S\cdot ln(1-\alpha_x)+4mV}\right]^{\frac{S_x}{S}} \cdot \left[\frac{0.16V}{-S\cdot ln(1-\alpha_y)+4mV}\right]^{\frac{S_y}{S}} \cdot \left[\frac{0.16V}{-S\cdot ln(1-\alpha_z)+4mV}\right]^{\frac{S_z}{S}}$$

Where α_x denotes the mean absorption coefficients of floor (S_{x1}) and ceiling (S_{x2}) given by

$$\alpha_x = \frac{\alpha_{x1}S_{x1} + \alpha_{x2}S_{x2}}{S_x} \qquad (4.17)$$

And

$$S_x = S_{x1} + S_{x2} \qquad (2.18)$$

α_y, α_z denote the mean absorption coefficients of the front-back and side walls, calculated respectively.

RT Design Criteria

The design process of large rooms and halls very often involve identifying desired reverberation times. Once target RT values have been selected, room geometry and the building materials are considered. iRoom provides an evaluation of known[1] room RT values and correlation with recommended reverberation times in respect to frequency and room type.

Predicated on existing RT design criteria, I have used curve-fitting algorithms to derive an equation describing the desirable RT in function of room volume and room type, given by

$$T_{60,recommended} = \kappa log_{10}(V) + \Delta \qquad (2.19)$$

Where κ and Δ are intermediate values representing the scaling and correction factor used to match Eq 4.19 to a specific type of room as shown in Figure 4-5.

i.e. measured and/or predicted [1]

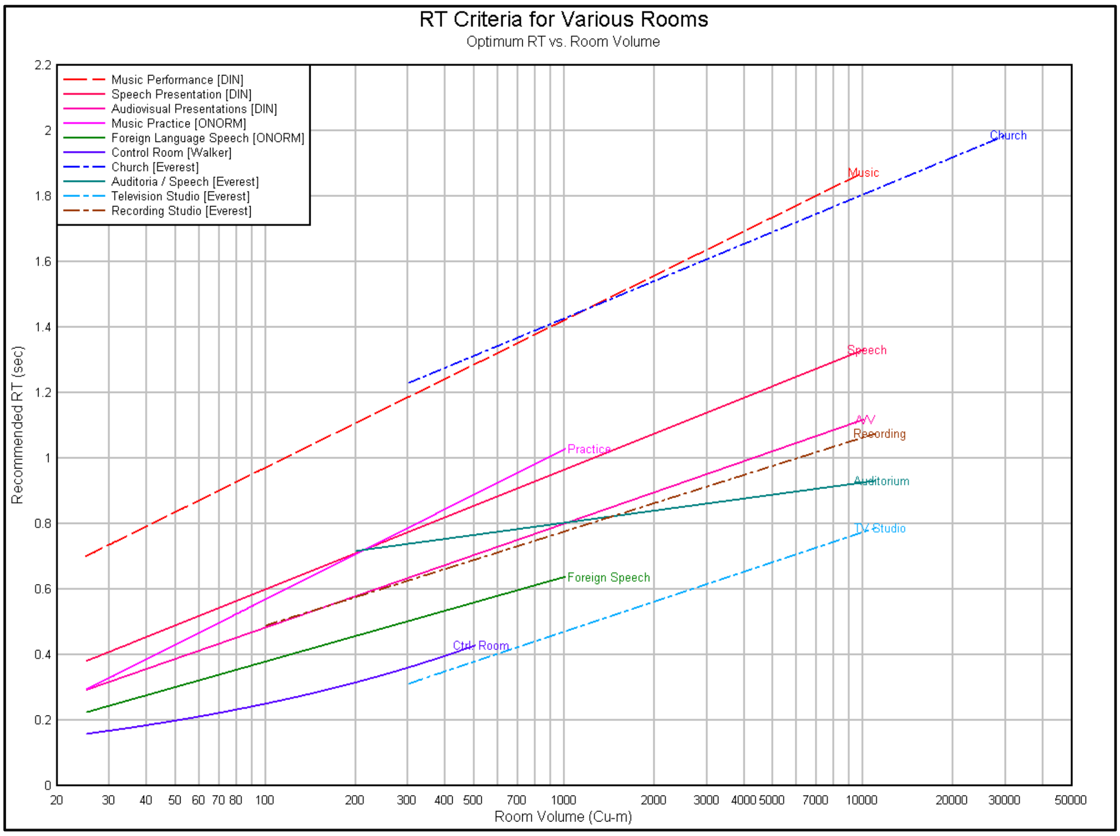

Figure 4-5 Recommended RT in function of Room Volume and Type

Criterion	***κ***	***Δ***	***Standard Error***
DIN 41018 (2004) – Music Presentation	*0.45*	*0.072*	*0.0049*
DIN 41018 (2004) – Speech Presentation	*0.365*	*-0.13*	*0.0032*
DIN 41018 (2004) – Audiovisual Presentation	*0.317*	*-0.151*	*0.0038*
ÖNORM B8115-3 (1996) – Music Practice	*0.4578*	*-0.3461*	*0.008*
ÖNORM B8115-3 (1996) – Communication Rooms	*0.324*	*-0.19*	*0.002*
ÖNORM B8115-3 (1996) – Foreign Language	*0.258*	*-0.137*	*0.0018*
Everest, F.A; (2001, p. 153) - Auditoria	*0.123*	*0.433*	*0.011*
Everest, F.A; (2001, p. 153) - TV Studios	*0.304*	*-0.442*	*0.01*
Everest, F.A.; (2001, p. 153) - Recording Studios	*0.287*	*-0.085*	*0.006*
Everest, F.A.; (2001, p. 151) - Church	*0.378*	*0.293*	*0.001*

Figure 4-1 Kappa and Delta values for Eq 4.19

An EBU report (Walker, Christensen, & Hoeg, 1997, p. 41) suggests an equation for calculating the desired reverberation times of control room, given by

$$RT_{cr}(V) = 0.25 \cdot \sqrt[3]{\frac{V}{100}} \qquad (2.20)$$

Some criteria describe a tolerance range for deviation from advised mean RT value, in function of frequency. In iRoom, these ranges are calculated and plotted whenever possible[1] along with the mean recommended value. When predicted or measured values are plotted together with the chosen design criteria, the deviation of existent data from desirable data may easily be observed, as further shown.

Depending on data availability [1]

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