rooms for speech. Good sight lines are important acoustically as they prevent absorption of the direct sound by grazing incidence over the heads of the audience. Much of the absorption of the sound in a room for speech (this reduces the reverberation) comes from the audience and seats and, for optimum reverberation times between 0.7s and 1.2s the room volume should be about $3m^3$/person. Because of the directional nature of the human voice the seats should lie within 140^0 angle width of the speaker.

Rooms for Music

Musicians employ many terms to describe the musical acoustic qualities of a hall e.g. warmth, said to be improved by a longer reverberation time at low frequencies. Music to be played in small halls, chamber music for a small number of musicians, is composed knowing there will be limited reverberation. Concert halls for large symphonies need much longer reverberation times to ensure the musical notes blend. Opera houses lie somewhere between. Typical reverberation times in large concert halls should be around 2s while those for opera houses in the range 1.4s - 1.7s. In these larger halls the reverberation time may be allowed to rise up to 50% at the low frequencies.

Early energy in music rooms is defined as the sound arriving within the first 80ms. The lateral energy fraction(LEF) is defined as the ratio of the sound energy picked up in the first 80 ms by a figure of eight microphone (aligned along axis through ears) compared to the total energy. There have been several subjective and (objective) surveys of concert halls. Barron (ref 5) used the attributes clarity, reverberance, envelopment, intimacy, loudness and balance developed as mutually independent criteria from earlier studies by Hawkes and Douglas(ref 6)) and Cremer and Muller (trans Shultz) (ref 1). Correlations of reverberance with the mean EDT over the bass and mid frequencies , envelopment with the lateral energy fraction (improved if bass total sound level and mid-frequency EDT is added), and intimacy with the early sound level (the sound level arising from the early energy).

Fan shaped halls provide little lateral energy and therefore poor envelopment. The traditional shoe box halls are known for having good acoustics and the lateral energy is high. It is cost restraints that have led to the abandonment of the shoe box but faceted reverse fan shapes such as the Royal Centre, Nottingham,UK (ref 7) and shoe box derivatives such as the new Birmingham Symphony Hall, Birmingham, UK (ref 8) have attempted to address this problem.

Calculation of Reverberation Time

Sabine's formula is generally used for the calculation of reverberation time unless the space is quite absorbing

R.T. = 0.16 x V/A where V is the volume of the room in m^3 and A the absorption area in m^2 or Sabines.

To calculate the absorption area, the absorption of the surfaces, any people or furniture, and air need to be taken into account although the latter, which is a function of the humidity of the air, can be ignored except at high frequencies in large spaces.

The absorption coefficient of a material (α) is defined as the fraction of incident energy not reflected. Whether this sound is absorbed or transmitted at the surface is unimportant for the room internal acoustics. The absorption area of a surface 1 given by:

$A_1 = \alpha_1 S_1$

where α_1 is the absorption coefficient of surface 1 with surface area S_1

For a room with n surfaces total surface absorption area $= \sum \alpha_n S_n$

A person contributes about $0.4m^2$ of absorption area @1000 Hz, and the absorption area per cubic metre of air is approx 0.003 m^2 @1000 Hz

Sabine's formula is derived assuming continual decay of sound. If we work out the mean free path in a space and assume that the sound decays when it strikes a surface a more accurate formula, Eyring's formula results. This gives a significantly different result if the sound absorption coefficient exceeds 0.2.

$R.T = -0.16V/S\ln(1-\alpha_m)$

where α_m is the mean absorption coefficient of the surfaces

These formulae only apply when the room dimensions are similar. They do not predict the behaviour in long low factories or long corridors. Calculation of theoretical reverberation time is never exact.

Sound Absorbing materials

These can be divided into three types:

1) Porous Absorbers
2) Panel or membrane absorbers
3) Helmholtz resonators

1) Porous Absorbers

These can be foamed open cell plastics, mineral fibre or similar usually compressed with a little glue, or sintered materials eg stone leaving an open pore structure. Absorption is essentially by friction of the sound wave within the open pores.

To understand a little more about absorption (and later transmission) it is worth introducing the concept of acoustic impedance. This is analogous to electrical impedance where you have an ac rather than dc supply (voltage divided by current). For plane waves it is simply the ratio of the sound pressure and the associated particle velocity and is equal to the density of the medium multiplied by the velocity of sound in that medium.