DOI: 10.61782/fa.2025.0059

FORUM ACUSTICUM EURONOISE 2025

ACOUSTIC CALCULATIONS AND WORKFLOW BASED ON LIST OF ACOUSTICALLY DISTINGUISHABLE SPACES

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ABSTRACT

Acoustic consulting often requires to make decisions and do calculations based on simplified data, such as list of rooms to support other relevant fields involved in the design of buildings. In general, a list of rooms contains a summary of data sheet for each room. For acoustic calculations basic geometry (floor area, height), comfort category, number and type of noise sources, exposure to adjacent disturbances, sound absorbing surfaces and objects etc. are useful. The paper provides an overview on what types of acoustically important aspects can be derived from such simple descriptions, using database relations, including room acoustics, sound isolation, MEP noise and electroacoustics. The aim is to create a simple to use integrated tool to increase efficiency and accuracy of the work of acousticians.

Keywords: *room list, architectural acoustic calculations, workflow optimization, room acoustics.*

1. INTRODUCTION

The design process is similar for solving any engineering problem: establishing requirements, assessing constraints, selecting solutions (materials, build-ups, details) to meet requirements, checking compliance by calculation, documenting the results (Figure 1).
It is no different in acoustics practice.
The author's own experience is that most of the time spent on design is spent searching for and organizing data, and that with no other solution at hand, this process is supported almost exclusively by his own collection of technical literature and Excel templates and MatLab routines.

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Moreover, the vast majority of tasks do not require complex calculations, while thoroughness requires that attention be paid to every room and structure of the planned facility.

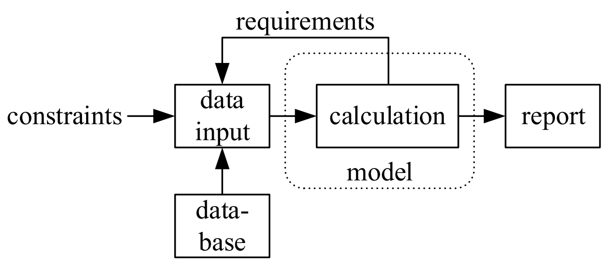

Figure 1. Generic design process.

According to the popular saying, a job can be done quickly, accurately and cheaply, but typically only two of the three aspects can be met.
The aim of the study is to find a more optimal workflow to support acoustic design, by developing a bespoke database-driven approach for generic situations.
Examples are given for room acoustic problems, but other disciplines of acoustics (e.g. sound isolation, MEP noise and isolation, electroacoustics, etc.) can be applied similarly.

2. KEY ELEMENTS OF THE WORKFLOW

The key to optimize design workflow is to a) find a repeatable and algorithmic representation of the problem and b) a scheme that requires minimum effort in calculations.

2.1 Data input: Room Schedules

The author found, that lists of acoustically distinguishable spaces (or room schedules) are the most effective interface to other engineering disciplines in terms of understanding, communicating and to specify generic architectural acoustic problems. With the appropriate support of databases, it can be the center of an efficient workflow in acoustics (Figure 2). A tabular representation of the most important data is easy to input, maintain, import, export or process further. Moreover, most related data (e.g. set of requirements, material properties) are also given in tabular formats anyway.

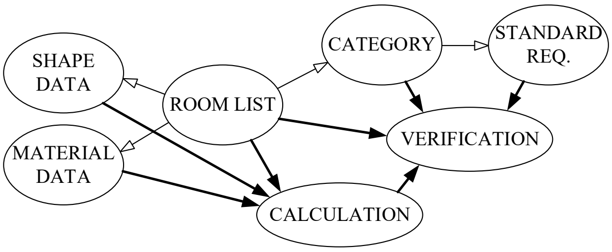

Figure 2. A room schedule (or room list) supported by appropriate databases can be the center of an efficient workflow (hollow arrow: reference, solid arrow: data).

2.2 Calculation Model: Accuracy vs. Complexity

The next question is then to find the minimum number of data, that are sufficient to describe each room in the list to meet the required accuracy of the set of specifications.
Generally speaking, the more effort (input data, complexity and quantity of calculation etc.) is put into a calculation model, the more it should approximate reality. Accuracy of a proper model is surely an asymptotic function of efforts, while the required resources will stay monotonically increasing (Figure 3).

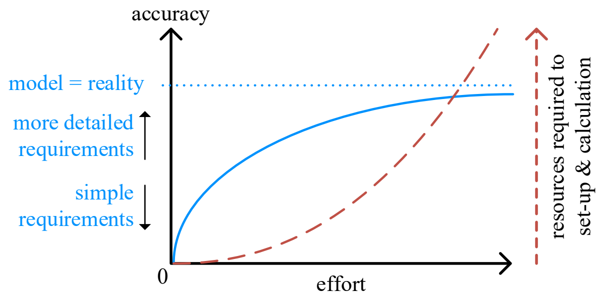

Figure 3. Generic hypothetical functions of accuracy and required resources vs. efforts put into a model.

2.3 Formulating Criteria: Generalization

From a purely engineering point of view, it is rather unfortunate, that still there is no unified and consensual set of metrics and thresholds in regulatory and standard documents yet. A generalization of requirements is therefore necessary in order to be able to adapt different regulatory schemes within the same project.

2.4 Databases: Generalization, Uncertainties

No calculation model is of much use, if there are no reliable databases of sound sources and materials. An acoustic calculation requires at least sound absorption data.
Sound absorption data in form of sound absorption coefficients or sound absorbing power are usually available in various forms (tabular, graphical) for surfaces meant for acoustic treatments in 1/1 or 1/3 octave resolution between 100Hz and 5kHz. Properties of generic ("non-acoustic") types of surfaces or objects are often found in literature, but more often can be estimated only. This resolution and dataset are acceptable, if the aim is to ensure a minimum quantity of absorption to meet usual acoustic requirement metrics. A metric for uncertainty would be nice, though.

2.5 Reporting

As soon as all the data and results are at hand, generating reports can be automated as well:
- summaries of requirements
- calculation results in the required details (tabular or graphic)
- bill of quantities.

3. ROOM ACOUSTIC CRITERIA

On a basic level, setting up room acoustic criteria should be an easy task, if there are any local regulations. The task is cumbersome, however, as soon as the situation is beyond the scope of local regulation or there are other types of standards to be considered.
The reason is, that room acoustic quality is expressed in many different ways with seemingly few consensual conclusions.

3.1 Acoustics Parameters vs. Input Data

Room acoustic criteria should be sorted in the order of complexity with respect to efforts (input data required, calculation complexity etc.) needed for verification.
An informative overview of the most common room acoustic parameters and the minimum required data for their estimation is shown in Table 1 (using [1], [2] and [3]). Important distinctions are around consideration of shape

(V/S ratio or different derivations of mean path lengths between reflections), effects of distance and directivity on early-late energy ratios.
As one can see, a fairly small amount of input data can be sufficient to estimate relevant quality descriptors.
Please note, that since standard measurements of room acoustic descriptors assume omnidirectional sources and receivers, directivity considers only the type of mounting (free, on or near wall, on or near corners etc.).
The next leap in calculation efforts is when mean path length and source-receiver distances are calculated in more detail. Nevertheless, requirements related to spatial deviations are rather rare and neglected in most room acoustic specifications.

Table 1. Overview of estimations of room acoustic descriptors with respect to input data required.

calculated parameter			required or considered input data										
			V	S_{total}	$S_{treatment}$	α	mpf	L, W, H	shape	T_{60}	Q_S	$d_{S>R}$	Q_R
sound absorption		A	-	-	X	X	-	-	-	-	-	-	-
sound absorption coefficient		α	-	X	X	X	-	-	-	-	-	-	-
reverberation time	Sabine	T_{60}	X	X	X	X	-	-	-	-	-	-	-
	Eyring	T_{60}	X	X	X	X	X	-	-	-	-	-	-
	Fitzroy	T_{60}	X	X	X	X	-	X	-	-	-	-	-
	Kuttruff	T_{60}	X	X	X	X	X	-	X	-	-	-	-
	Fürjes	T_x	-	X	X	X	X	-	X	-	X	X	-
total level	Sabine	L	X	X	X	X	-	-	-	-	X	X	-
	Barron	L	X	X	X	X	-	-	-	X	X	X	-
	Rychtárikova	L	X	X	X	X	X	-	-	-	X	X	-
	Fürjes	L	-	X	X	X	X	-	X	-	X	X	-
early-late level	Barron	L_{te}	X	X	X	X	-	-	-	X	X	X	-
	Fürjes	L_{te}	-	X	X	X	X	-	X	-	X	X	X
gain	Sabine	G	X	X	X	X	-	-	-	-	X	X	-
	Barron	G	X	X	X	X	-	-	-	X	X	X	-
	Fürjes	G	-	X	X	X	X	-	X	-	X	X	X
clarity	Barron	C_{te}	X	X	X	X	-	-	-	X	X	X	-
	Fürjes	C_{te}	-	X	X	X	X	-	X	-	X	X	X
early-decay time	Fürjes	EDT_{10}	-	X	X	X	X	-	X	-	X	X	X

3.2 Mean of Frequencies

Acoustic parameters depend on frequency. Single value requirements use arithmetic means, direct weights or tolerances with allowed deviances across frequency bands.
For room acoustic parameters, the 'mean' value in most cases means the arithmetic mean of values at different frequency bands. Usually, 1/1 octave bands, namely 250 Hz, 500 Hz, 1 kHz and 2 kHz bands are considered.
The author denotes $m1$ if 500 Hz, $m2$ if 500 Hz and 1 kHz, $m3$ if 500 Hz, 1 kHz and 2 kHz and $m4$ if all the four octave bands are used. Please note, that notation might change from standard to standard and using arithmetic means might be just a formal habit with no physical meaning (e.g. summing decay times or energy ratios).
Unfortunately, if different standards need to be applied at the same time, a conflicting definition of 'mean' cannot be resolved, because neither type of mean is more inclusive than the other. On the other hand, measured results show low deviation of different means (e.g. $m2$ vs. $m4$).
Definition of a mean requires flagging considered frequency bands and the type of calculation (arithmetic mean, harmonic mean, power mean), in the form like $\{m_{31.5Hz} \dots m_{8kHz}; m_{type}\}$ for each parameter type.

3.3 Mean Sound Absorption (A_m)

A requirement of minimum of sound absorption represents the aim to reduce noise levels within the rooms. A general form based on formulas found in standards (e.g. [4], [5]) could be

$$A_m \geq \frac{a_A}{[1+b_A \cdot log_{10}(H/H_0)]} \cdot V + c_A \cdot S + d_A \cdot S_f \quad (1)$$

where A_m is the mean sound absorption requirement, V is the volume of the room, S is the total surface area of the room, H is the height of the room, $H_0 = 1m$, S_f is the floor area in the room and $\{a_A; b_A; c_A; d_A\}$ are parameters depending on the category of the room.
The above formulation considers only architectural surfaces (i.e. not air absorption, not furniture or occupants), meaning that c_A is actually the average absorption coefficient $\bar{\alpha}_{arch}$ of architectural boundaries.
For example, a requirement of MSZ2080 (see [6]) of $A_m/V \geq 0.20\frac{m^2}{m^3}$ of corridors with max. 3.2 m height can be translated to $\{0.20; 0; 0; 0\}$ terms. Similarly, a $\alpha_{m2} \geq 0.30$ requirement is translated as $\{0; 0; 0.30; 0\}$ or a DIN18041:B2 $h > 2.5m$ situation $A/V \geq [4.8 + 4.69 lg(h/1m)]^{-1}$ is translated to $\{0.208; 0.977; 0; 0\}$ terms.

3.4 Mean Reverberation Time (T_m)

A maximum reverberation time or maximum length of sound level decay requirement is a simple tool to limit detrimental effects caused by late or ongoing reflections. Also, it is a very illustrative descriptor to both non-professionals and musicians.
As an overall ruler, a limited reverberation time will also limit other quality descriptors in favor of higher early/late energy ratios. That explains most correlations found with other parameters.
Please note, that while definitions of T_{60} rely on the *length* of sound decay, estimations except given in [3] approximate

the *slope* of the decay only, which are not the same. The difference in these is significant only when the early/late energy ratio is affected by directivity or local reflections at either the source or receiver side.
Using formulas found in standards (e.g. [4], [7]), one may use the general formula of setting maximum mean reverberation time requirement as

$$T_m \leq a_T \cdot log_{10}(V/V_0) + b_T \cdot (V/V_0)^{c_T} + d_T \quad (2)$$

where T_m is the mean reverberation time requirement, V is the volume of the room, $V_0 = 1m^3$, and $\{a_T; b_T; c_T; d_T\}$ are parameters depending on the category of the room. For example, a DIN18041:A2 requirement is described by $\{0.37; 0; 0; -0.14\}$. In addition, these forms also come with a minimum and maximum of V or T_m.
To the author's knowledge, both the parameters and the formulas used in standards are empirically chosen with no direct physical explanation.
A minimum mean reverberation time requirement can be added where an acoustic source needs support from reverberation in the room.

3.5 Reverberation Time Frequency-Dependence

Requirements controlling frequency dependence of reverberation time have usually the same mission, but differ significantly from standard to standard (Figure 4). The aim of using tolerances is to keep deviation from a mean reverberation time to a reasonable minimum as a function of frequency, while allowing longer reverberation at low frequencies to support moderately loud operation and to avoid excessive high frequency attenuation overall.
Frequency dependent specifications can be absolute (e.g. [8], [9], [10]) or adjusted to the mean reverberation time by a ratio (e.g. [4], [11]) or a difference (e.g. [7]).
For the sake of simplicity, tolerances can be considered at 1/1 octave bands only. This way, a tolerance requires values to specify minimum and maximum for each frequency band, and a flag if is related to the mean value.

3.6 Considering Room Conditions

Conditions of occupancy (in percentage) and furnishing ("yes" or "no") must be clearly stated in a definition of room acoustic criteria, because these have significant effect on their interpretation.
Atmospheric conditions are usually not mentioned in standards of room acoustics. This is important however to set for frequency dependent tolerances, because deviations in temperature or relative humidity can cause room acoustic parameters to change noticeably (>5%) at 2 kHz and higher frequencies (see [12]).

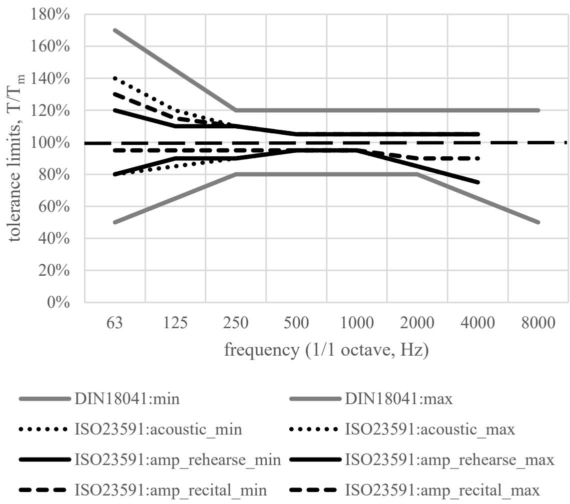

Figure 4. Mean-related frequency-dependent tolerances of reverberation times are different.

3.7 Additional Criteria

Additional technical parameters can be used to refine expectation of room acoustic qualities.
Loudness of reverberation can be expressed as the actual reverberating sound level relative to the free-field sound level of a sound source. This is called Gain, defined in [13], given in dB, used in [11]. Frequency dependence is not considered.
The ratio of early/late energy portions of an impulse response in dB correlates to perception of clarity (see [13]). Minimum mean speech clarity like $C_{50,m3}$ (see [14]) uses early-late time limit of $t_e = 50ms$. Frequency dependence is not considered.
Perceivable acoustic parameters change also from position to position within a room. Parameters discussed so far assume a spatial average, though requirement standards usually are not explicit in this respect or refer to definition standards.
Spatial decay rate is an important issue for open spaces with multiple simultaneous activities. By using distance-dependent estimations of room acoustic effects, requirements like $D_{A,S}$ (in-situ attenuation of speech) or $D_{2,S}$ (spatial decay rate of speech) of [9] can be calculated. Frequency dependence is not considered, A-weighting is used.
Calculation of sound level requires the sound power level L_w of the source and its directivity factor Q, or if Q is not of concern, the free-field sound level at a reference distance to be known. For example, $L_{p,A,S,4m}$ (A-weighted sound

pressure level of speech at 4 m) of [ISO22955] is defined by a reference sound level at 1 m distance for octave bands.
Preferred ratios of dimensions can be used to avoid unfavorable situations, like e.g. uneven frequency response at low frequencies due to modal behavior (see [11], [7], [15]).
A generic form of these requirements can be:

$$sign(a_R \cdot L + b_R \cdot W + c_R \cdot H) = d_R, \quad (3)$$

where for example equality of [11] $L/H = 2.36\,W/H - 1.38$ can be translated to $\{1; -2.36; 1.38; 0\}$ or unequality of [7] $1.1 \cdot W/H \leq L/H$ can be translated to $\{1; -1.1; 0; 1\}$.
In cases, where room conditions require to define occupancy and the number N of occupants is known, ratios of N/S_f or N/V can by added to the set of requirements, because occupants have a significant effect on room acoustics.

4. CALCULATION FORMULAS

4.1 Main Dimensions

For box-shaped rooms, main dimensions of L, W and H can be read from drawings and volume V, surface S, floor area S_f can be calculated easily.
Dimension-related criteria can be verified directly.
The mean path length between reflections in a box-shaped volume is

$$\bar{l}_{stat} = 4\,V/S, \quad (4)$$

which can be derived in different ways (e.g. [1]), even using mirror image sources (i.e. not assuming diffuse reflections). This suggests, that multiple different reflection paths can be approximated by a single repeating reflection with length $\bar{l}_{stat}$ and $\bar{l}_{stat}/c$ average time, when c is the speed of propagation.
Room schedules often present only floor area S_f and height H. With no further information, an estimation of $L = W = \sqrt{S_f}$ can be used as a worst-case scenario, because a square floor area has the highest V/S ratio and longest $\bar{l}_{stat}$ estimation of box-shaped geometries.

4.2 Room Shape

The author found, that formulas can be rewritten meaningfully when normalizing the mean path length $\bar{l}_{stat}$ and source-receiver distance r by $\sqrt{S}$:

$$\bar{l}_n = \bar{l}_{stat}/\sqrt{S} = 4\sqrt{V^2/S^3} \quad (5a)$$

$$r_n = r/\sqrt{S} \quad (5b)$$

The importance lies in the fact, that $\bar{l}_n$ depends only on the shape of the room, but not its dimensions, like a shape factor.
If the room is not rectangular or absorption is extremely irregular (e.g. open ceiling), estimation of $\bar{l}_{stat}$ or $\bar{l}_n$ requires more complex calculations.
This is where using prepared simple convex volumetric shape-models can help. Using only a specification like $\{L_1; W_1; H_1; L_2; W_2; H_2; X_1; X_2\}$ (see Figure 5) can describe most typical situations convincingly, without the need to build 3D room acoustic models. Values of X_1 and X_2 can be additional sizes or the number of segments approximating continuous arcs.
Shape-models are then useful also to generate valid source and receiver positions and from that, valid source-receiver distances and effects of source directivity can be considered as well.

4.3 Sound Level

The sound level L_p consists of the direct sound and the sum of reflections.
Classic theory suggests, that the sum level of reflections is constant across the room:

$$L_p = L_w + 10 \cdot log_{10}\left[\frac{Q_{SR}}{4\pi \cdot r^2} + \frac{4}{A}\right], \quad (6)$$

where L_w is the sound power level of the source, r is the distance, Q_{SR} is the directivity factor for the given source-receiver constellation and A is the total sound absorption of the room.
A is simply the sum of A_S absorption of boundaries, A_O absorption of objects and A_V absorption of the volume:

$$A = A_S + A_O + A_V. \quad (7a)$$

Absorption of boundaries A_S can be calculated as

$$A_S = -ln(1 - \bar{\alpha}) \cdot S, \quad (7b)$$

using the Eyring-formula, and

$$\bar{\alpha} = \alpha_0 \cdot (S - \sum S_i) + \sum \alpha_i \cdot S_i \quad (7d)$$

where $\bar{\alpha}$ is the average sound absorption coefficient of surfaces, α_i is the sound absorption coefficient of the material with surface S_i and α_0 is the sound absorption coefficient of the default (untreated) surface. Obviously, condition $S \geq \sum S_i$ must be preserved.
Absorption of free-standing objects is

$$A_O = \sum A_j \cdot n_j, \quad (7c)$$

Where A_j is the sound absorption and n_j is the quantity.
Absorption of the volume is

$$A_V = 4 \cdot m \cdot V, \quad (7d)$$

where m is the sound absorption of the air.
Room schedules include references to material databases and quantities S_i and n_j. Material databases contain frequency-dependent properties α_0, α_i and A_j. Absorption of air can be calculated from standards, but must be converted from single-frequency values to 1/1 octave band values beforehand (see [12]).

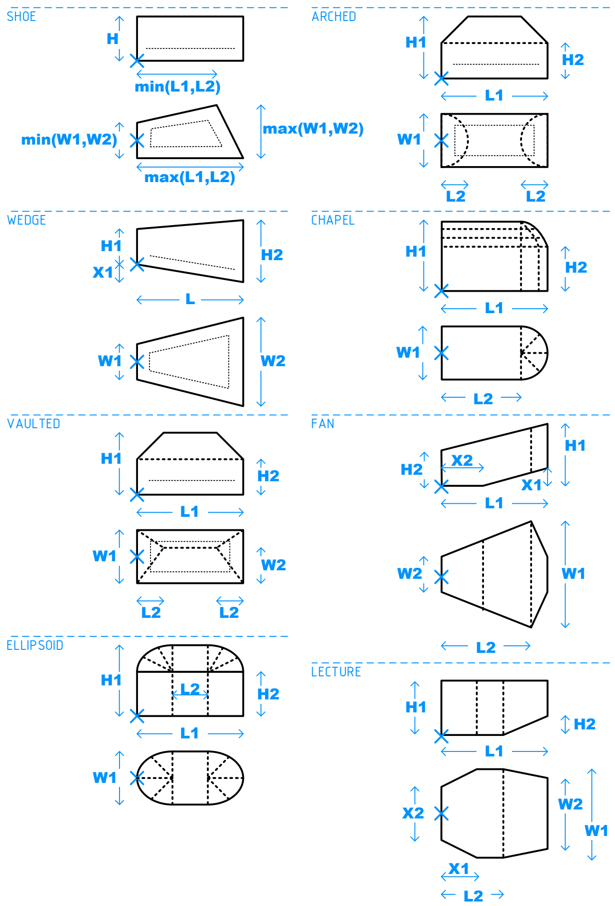

Figure 5. Typical convex room shapes for fast entry and calculation of shape-dependent parameters.

More recent approximations follow the experience (see [2]), that sound level of reflection is not constant across the room, but decrease with distance. Classic theory in (6) still can be used for worst-case approximation of noise levels.
Revised approximation of sound level, considering shape-factor (see [3]) is

$$L_p = L_w + 10 \cdot log_{10}\left[\frac{Q_{RS} \cdot e^{-m \cdot r}}{4\pi \cdot r_n^2} + \frac{4 \cdot (1-\alpha^*)^{r_n/\bar{l}_n + 1}}{\alpha^*}\right] - 10 \cdot log_{10} S, \quad (8)$$

where $e^{-m \cdot r}$ is the sound absorption of the air to the direct sound, and the total average sound absorption α^* includes sound absorptions of surface, objects and air.
It is important to see, that according to Eq. (8), reverberating sound level depends more on absorption α^*, shape r_n/l_n and total surface area S, than volume V.
Equation (8) has been tested and found following measured tendencies well (see [3]) and can be completed by adding Waterhouse-correction $C_W = 10 \cdot log_{10}(1 + 2\,\lambda/\bar{l})$ at low frequencies and small rooms when necessary.

4.4 Reverberation Time as Decay Rate

Classic theory suggests, that reverberation time governed by reverberating volume and absorbing power:

$$T_{60,stat} = 24 \cdot ln(10) \cdot \frac{V}{A}, \quad (9a)$$

which can be rewritten in the form

$$T_{60,stat} = 6 \cdot ln(10) \cdot \frac{\bar{l}}{c} \cdot \frac{1}{\bar{\alpha} + [A_O/(4 \cdot V) + m] \cdot \bar{l}}. \quad (9b)$$

The latter form reflects, that temporal rate of decay depends on the average time $\bar{l}/c$ spent between reflections the average energy loss α^* during each cycle, as

$$\alpha^* = \bar{\alpha} + [A_O/(4 \cdot V) + m] \cdot \bar{l}. \quad (10)$$

If $\alpha^* > 1$, $\alpha^* = 1$ must be used.
It is important to note, that $T_{60,stat}$ is not the length, but the rate of decay of reverberation. This is why it is valid to consider it constant across the volume of the room, as long mean path length and characteristic absorbing properties are seen constant across the volume of the room.

4.5 Reverberation Time as Measured

At any point in a room, the response is a sum of the direct sound and the sound coming from reflections. When the source is visible to the receiver, direct sound always arrives first, reflected sound follows. Energy-time response (ETC) can be converted to the energy decay curve (EDC), which is the ratio of remaining energy of the response and the total energy of the response (see Figure 6).
When reverberation time T_{60} is defined as a length of the response where EDC drops below -60 dB, it can be calculated as

$$T_{60} = \frac{60dB + EDC_{t_{0+}}}{60dB} \cdot T_{60,stat} \quad (11a)$$

where $EDC_{t_{0+}}$ is the first drop in EDC

$$EDC_{t_{0+}} = -10 \cdot log_{10}\left[1 + 10^{DRR/10}\right] \quad (11b)$$

and DRR is the ratio of the direct sound and the reflected sound

$$DRR = 10 \cdot log_{10}\left[\frac{Q_{SR} \cdot \alpha^*}{16\pi \cdot r_n^2 \cdot e^{m \cdot r} \cdot (1-\alpha^*)^{r_n/l_n + 1}}\right]. \quad (11c)$$

Measured reverberation time according to [13] is a linear regression of the EDC between two points. For example, reverberation time T_{20} from the of EDC -5 dB and -25 dB points can be approximated as

$$T_{20} \approx \frac{(25dB + EDC_{t_{0+}}) \cdot (15dB - EDC_{t_{0+}})}{25 \cdot 15\ dB^2} \cdot T_{60,stat} \quad (12)$$

assuming that $EDC_{t_{0+}} > -25$ dB (i.e. response contains enough reverberant energy).

This approach explains, how different reverberation time definitions relate to each other (see Figure 7) and agrees well with measured tendencies.

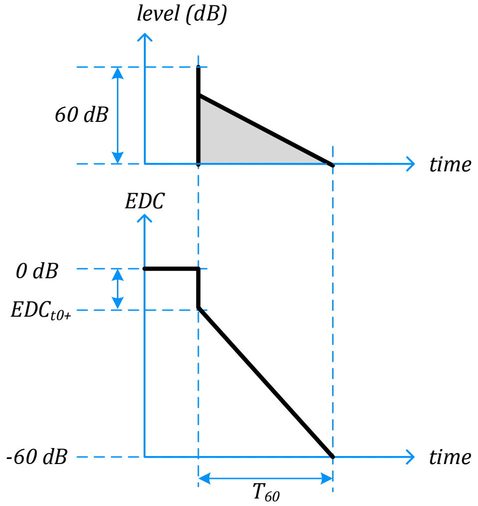

Figure 6. The simplest form of response shown as energy time curve (ETC) and energy decay curve (EDC).

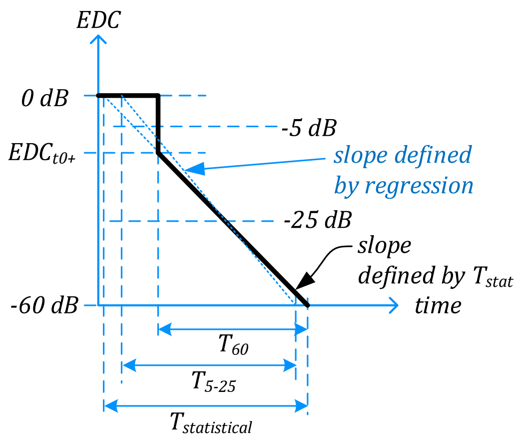

Figure 7. Comparing different reverberation times.

4.6 Early Decay Time as Measured

In a similar manner, early-decay time EDT_{10} can be approximated, when $EDC_{t_{0+}} > -10$ dB as

$$EDT_{10} \approx \frac{(10dB+EDC_{t_{0+}})\cdot(10dB-EDC_{t_{0+}})}{10\cdot 10\ \text{dB}^2} \cdot T_{60,stat} \quad (13)$$

assuming that $EDC_{t_{0+}} > -10$ dB. This condition explains also, why evaluation of EDT_{10} can be ambiguous when DRR is high.

4.7 Early-Late Ratios

Early-late ratios can be taken directly from EDC at any given early-late t_e time limit from the onset of the direct sound (t_{0+} point):

$$C_{t_e} = 10 \cdot log_{10}\left(10^{-EDC_{t_e}/10} - 1\right), \quad (14a)$$

where

$$EDC_{t_e} = EDC_{t_{0+}} - \frac{t_e}{T_{60,stat}} 60\text{dB}. \quad (14b)$$

4.8 Parameters Considering SNR

Certain standards use speech transmission index (STI) in order to specify speech clarity requirements. STI is not a room acoustic measure, but a parameter for electroacoustic transmission, as it is developed to consider signal to noise ratios (SNR) and possible distortions along the transmission, with many correction options for perceptual masking or non-native speaker issues for example. If STI is applied assuming linear transmission, without perceptual corrections, an STI requirement will implicitly call for a minimum signal-to-noise ratio as well.
Without considering SNR, measurement results show STI to correlate many of the room acoustic parameters fairly well (see [17]). The tendency is, that STI correlate early-late ratios directly within ± 0.05 error, while reverberation time allows a 'worst case' STI estimate:

$$STI_{C_{80}} \approx 0.022 \cdot C_{80,m4} + 0.53, \quad (15a)$$

$$STI_{EDT_{10}} \approx -0.165 \cdot ln\left(EDT_{10,m4}\right) + 0.594, \quad (15b)$$

$$STI_{T_{20}} \geq -0.2 \cdot ln\left(T_{20,m4}\right) + 0.55. \quad (15c)$$

When SNR must be considered, a better option is to calculate useful-to-detrimental ratio

$$U_{50} = 10 \cdot log_{10}[E_0^{50}/(E_{50}^{\infty} + E_N)] \quad (16a)$$

or

$$U_{50} = C_{t_e} - 10 \cdot log_{10}\left[1 + \frac{10^{-SNR/10}}{10^{-EDC_{t_e}/10}}\right], \quad (16b)$$

where $SNR = L_p - L_N$ and $t_e = 0.05s$.
According to [16]

$$STI \approx 0.114 \cdot U_{50} - 0.54 \quad (16c)$$

is a good estimate.

4.9 Application

Figure 8 shows an example of graphic report of calculation results of T_{20} reverberation time when applying the "lecture" shape. Setting up and running similar calculations can happen in real time for all listed parameters. Most of the work is done by checking input data and setting up requirements. More advanced calculation methods (low order image sources, diffuse radiosity) for better precision can also happen in seconds, but can be run in batch mode, after setting up the room schedule.

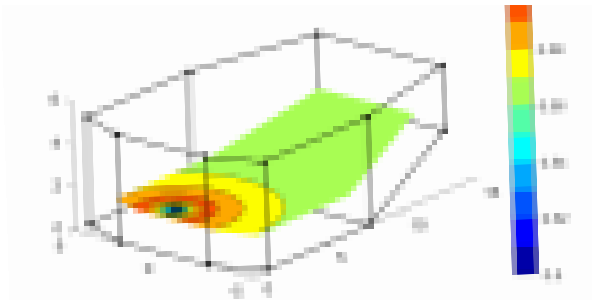

Figure 8. Calculation example: reverberation time T_{20} in a "lecture" shape with dimensions {15;10;5;8;7;2;1;5} and {0.40;0.10;0.50} absorption coefficients on the floor, walls and ceiling respectively, from one omni source

5. SUMMARY

It is important in acoustic engineering practice to be efficient and thorough at the same time, in order to fulfill the ever-growing number of acoustic requirements. Calculation schemes, however are not scalable: one either uses oversimplistic statistical formulas in spreadsheets with minor efforts or creates acoustic models with disproportionate efforts required. Diverse formulation of requirements in different standards and recommendations is also a problem.
The paper suggests to use room schedules, which can be used to generate simple models for calculations. Room schedules are usually available from architectural data, but even the cost of manual data input or its maintenance should not be a problem in most cases.
Most relevant acoustic requirements can be verified using revised formulas without the computation cost of conventional acoustic modelling. Results can be used to generate reports in any required format from graphical representations to simple spreadsheets of bill of quantities.
The next step is to interface to more advanced calculation methods and add functionalities of other fields of acoustics (noise, sound isolation, PA). Also, simple algorithms can suggest solutions or indicate weaknesses automatically.

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