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PRESENTS

Music Room Acoustics – Critical Parameters

Toward a new standard

by M Skålevik

SUMMARY

An enormous variety of music room sizes appears to be the main challenge in the work towards a new standard for music rooms. The field of music room acoustics has been dominated by the large concert hall case, which is to be considered a special case, and whose parameters are not proven to have general relevance valid for the great variety of music rooms. In particular, it is not fruitful to use parameter values recommended for big concert halls as ideals for the general music room.

This paper is an attempt to approach a set of acoustical quantities that can describe the acoustic quality of small, medium to large size rooms for musical rehearsal and performance, taking the great variety of common music styles into account. One aim is to be able to use such a set of parameters to achieve equal experienced quality in two music rooms of equal use even if they vary significantly in geometry and surface properties.

It is advised to consider approaching some form of quantity for running reverberation when choosing parameters to describe the perception of Reverberance in the great variety of music room size. Observation tends to indicate that while EDT describes Reverberance in the large concert halls, it does not necessarily do so in music rooms in general.

A requirement for volume related to ensemble size in music spaces, i.e. the Nominal Ensemble Size N=V/(100T), is suggested as an addition to existing Norwegian standards. It is concluded that the addition provides consistent loudness control throughout the span of music room volumes. In further work a similar requirement for music practice rooms is to be established, supposedly in the region V/(80T) and V/(20T).

The Pyramid of Acoustic Needs is suggested, as an aid for development of music room requirements. A consequence of the Pyramid is that it makes no sense to bring in requirements for Reverberance, Clarity, Envelopment, Apparent Source Width, etc, before Loudness is under control. This fact emphasizes the importance of introducing the nominal ensemble size requirement suggested in this paper.

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Music Room Acoustics – Critical Parameters

Toward a new standard

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The Norwegian standard NS8175, Acoustic conditions in buildings - Classification of various types of buildings, plays an important role in acoustic design in the Norwegian building industry. Up to present, the standard has not included any recommendations or requirements for acoustics in music rooms other than this comment to the T=0.6s requirement in rooms in schools and other educational purpose: “In rooms for song and music, a longer reverberation time may be proper”. Recommendations in terms of materials, surface treatment and acoustical parameters like reverberation times and acoustic absorption can be found in the literature, but hardly conclusive and consistent throughout. This paper is an attempt to approach a set of acoustical quantities that can describe the acoustic quality of small to medium size rooms for musical rehearsal and performance, taking the great variety of common music styles into account. One aim is to be able to use such a set of parameters to achieve equal experienced quality in two music rooms even if they vary significantly in geometry and surface properties. The acoustical hierarchy of needs (pyramid of acoustical needs) is introduced. A requirement for volume related to ensemble size in music spaces, i.e. the Nominal Ensemble Size N= V/(100T), is suggested as an addition to existing Norwegian standards. It is concluded that the addition provides consistent loudness control throughout the variety of music room volume.

1 Introduction

The Norwegian standard NS8175, Acoustic conditions in buildings - Classification of various types of buildings [1], plays an important role in acoustic design in the Norwegian building industry. Up to present, the standard has not included any specific recommendations or requirements for acoustics in music rooms. Recommendations in terms of materials, surface treatment and acoustical parameters like reverberation times and acoustic absorption can be found in the literature, but hardly conclusive and consistent throughout.

Many of the parameters established for describing acoustics of performance spaces, e.g. ISO 3382, are valid in the large concert hall case, in which T, EDT, V, G and ensemble size exhibits relatively little variation throughout the preferred halls. Music room acoustics research has, for many natural reasons, been dominated by large concert hall acoustics research, where many of the parameters important to music perception in practice act like constants [1]. General relevance of the set of parameters in ISO 3382, in particular the wide span of space and ensemble size in music rooms, is not confirmed.

This paper is an attempt to approach a set of acoustical quantities that can describe the acoustic quality of small to medium size rooms for musical rehearsal and performance, taking the great variety of common music styles into account. One aim is to be able to use such a set of parameters to achieve equal experienced quality in two music rooms even if they vary significantly in geometry and surface properties. In this first approach, basic room acoustical parameters are addressed, especially those depending on the Brief, the overall geometry and the hard-to-change properties of the room, such as volume per person.

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[1] A parameters is per definition a variable that is being kept constant during a study of other variables

Though this author is a member of the work-group of the music room standard, and though the content of this paper is consistent with the agenda and mandatory of the work-group, this paper is solely the expression of the views of its author.

2 Present requirements, recommendations and standards in Norway

Up to present, there are in Norway three major national reference documents relevant for design of music rooms. These documents are especially important since they often serve as reference criteria for planning permissions, building permit and government funding of culture buildings.

2.1 Standards Norway,

Document: Norwegian Standard NS 8175, Acoustic conditions in buildings - Classification of various types of buildings [1].

Up to present, the standard has not included any specific recommendations or requirements for acoustics in music rooms other than some comments to the maximum T=0.6s requirement in rooms in schools and other educational purpose: “In rooms for song and music, a longer reverberation time may be proper”. In the 125Hz octave, the

Since 2012 a work-group is formed with the mandatory to develop a new standard for music rooms.

2.2 NBI: SINTEF Byggforsk (National Building Research Institute),

Document: Byggdetaljblad 527.300 Romakustikk. Guidelines for room acoustics in rooms for speech, music and sound reproduction [2].

2.2.1 Guidelines

Guidelines for basic properties of music rooms include recommended reverberation times T for unreinforced music, and for room proportions in terms of Height:Width:Length, both as a function of room volume, see Figure 1. Volume per listener is required to be in the interval 6-12m^3.

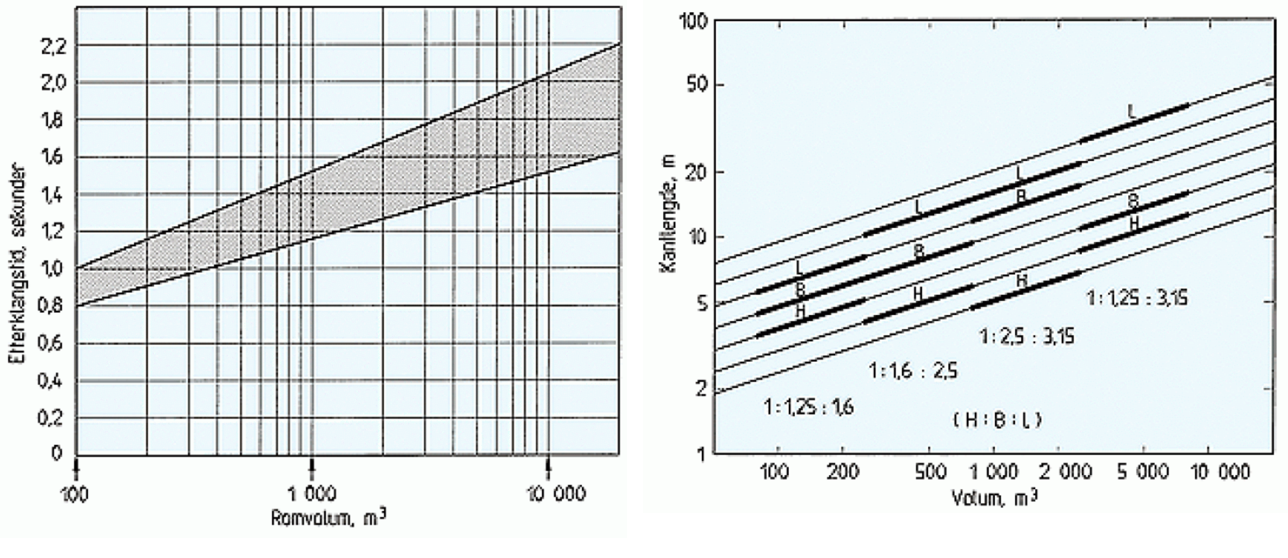

Figure 1 Recommended reverberation times T(s) for unreinforced music (left) and room proportions (right) for rectangular halls, in terms of Height:Width:Length (H:B:L), as a function of room volume V(m^3) (NBI 527.300)

2.3 NMR: Norsk Musikkråd (Norwegian Music Council),

Normer og Anbefalinger (Standards and Recommendations), Oslo 2010 [3].

2.3.1 Standards and Recommendations

The recommendations address practice rooms and performance venues, with recommendations as follows:

1) Practice rooms and performance venues: Volume-related recommended reverb time intervals in for three categories of musical power, Figure 2.
    a. Quiet groups (choir, soloists, string-quartets, ensembles up to N=10)
    b. Powerful groups (school bands up to N=40-50, amateur bands N=25-30, big-bands, basically non-reinforced instruments)
    c. Reinforced music (pop/rock with PA sound production)
2) Performance venues
    a. Length, width, heights
    b. volume per person
    c. stage area per instrument depending on type of instrument
    d. stage height
    e. criteria for coupling between stage and auditorium
    f. multipurpose venues, required volume per person (performers + listeners) in the interval 7-10m^3.

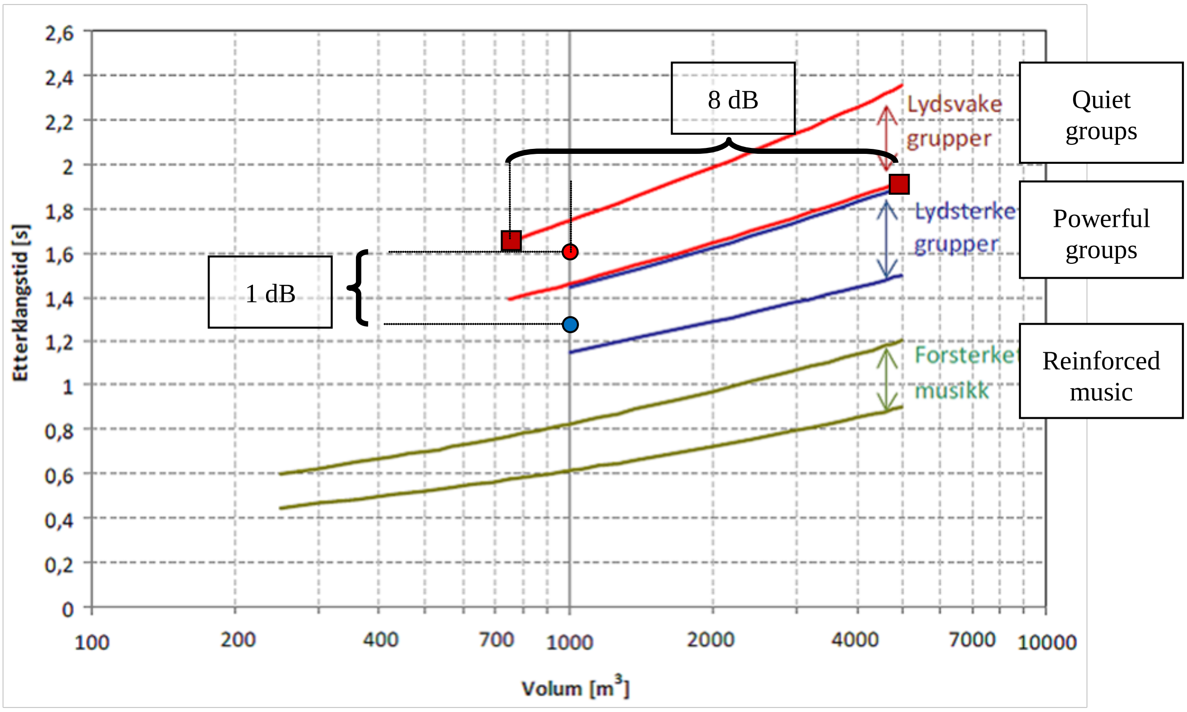

Figure 2 Recommended reverberation times T(s) as a function of room volume V(m^3) for three categories of ensemble power (NMR)

3 Comments and potential development of existing standards

In this section, the existing standards, guidelines, requirements and recommendations referred to in section 2, are commented, and their potential for development into a consistent standard is discussed.

The curves for powerful groups in Figure 2 are very similar to guidelines by NBI in Figure 1.

This author comments that the recommendations contribute relevantly to a consistent standard with a potential for being developed to a higher degree of repeatability. The main improvement potential lies in loudness control. As per today, on average only 1dB difference in loudness is expected to be measured in a room qualified for non-powerful music and the same room with reverb adjusted to accommodate for powerful music, see Figure 2. In contrast, on average 8dB difference in loudness level is expected between two different rooms qualified for non-powerful music, due to the allowed differences in T/V ratio. This inconsistency can be solved by instead of trying to control loudness by ineffective changes in reverberation time, loudness can be controlled by relating the room acoustic response, which is governed by the ratio T/V, to the ensemble size N, according to the suggestion given in this paper.

NBI and NMR have practically the same standards for volume per person, but both fail to relate volume V to ensemble size N, thus loudness is out of control. By carefully deducing the ratio of ensemble size and audience size from room ratios recommended by NBI, volume per listener by NBI, and area requirements per musician by NMR, it can be shown that a consistent loudness throughout varying V and T can be achieved.

As an example, room acoustical loudness level could easily be kept consistent throughout different combinations of T, V and N, by simply adding the volume requirement V=100T ·N, or expressing the nominal ensemble size of a music performance room by N=V/(100T). Nominal ensemble size of a powerful group playing in a V=5000 room with T according to Figure 2 be N=5000/(1001.7)=26 -33. Compared to this, NMR exemplifies “powerful groups” by an N=25-30 amateur band. Without the nominal ensemble size requirement, such a band would be allowed to produce 8dB excess loudness in the 1000m^3 room.

Geometrical and acoustical parameter values satisfying NBI and NMR criteria referred to above, when adding the ensemble size requirement N=V/(100T), is presented in Table 1. Note the very small variation in loudness levels L(N) as a result of introducing ensemble size requirement. The high percentage (up to 52%) of unused floor area (Sr) in rooms in the volume range 400-1600m3 call for more detailed investigation in further work. This is partly related to the unmotivated high W/H ratio of 2.5. By “smoothing” the recommended Height, Width, Length to their best fit lines, Figure 3, unused area percentage drops to 32% at 1600m^3 and a maximum occurs by 42% at 400m^3.

The NMR categories “quiet” and “powerful” will need to be replaced or redefined in order to solve the inherent self-contradicting loudness criteria.

An overview of parameter data from existing halls of various volume, and recommendations, was presented by Buen[9].

Table 1: Geometrical and acoustical parameter values satisfying NBI and NMR criteria referred to above, when adding the ensemble size requirement N=V/(100T). Resulting loudness L(N) in dB, at nominal distance Rnom, from an ensemble of size N in the rightmost column. Parameter abbreviations are explained in text.

V	T	W/H	L/H	H	W	L	V/(TN)	N	Na	Sr	V/Na	V/Nt	A/N	T/H	Rnom	G	C80	L(N)
100	0,9	1,25	1,6	3,7	4,6	5,9	100	1	13	33 %	7,6	7,0	16	0,24	2,9	24	4	25
200	1,0	1,25	1,6	4,6	5,8	7,4	100	2	26	40 %	7,6	7,1	16	0,22	3,7	22	3	25
400	1,2	1,6	2,5	4,6	7,4	12	100	3	53	52 %	7,5	7,1	16	0,26	5,8	19	2	24
800	1,3	1,6	2,5	5,8	9,4	15	100	6	108	47 %	7,4	7,0	16	0,23	7,3	16	1	24
1600	1,5	2,5	3,15	5,9	15	19	100	11	215	51 %	7,5	7,1	16	0,25	9,3	14	1	24
3200	1,6	1,25	3,15	9,3	12	29	100	20	434	25 %	7,4	7,1	16	0,18	15	11	0	24
6400	1,8	1,25	3,15	12	15	37	100	36	868	8 %	7,4	7,1	16	0,15	19	8	0	23
12800	1,9	1,25	3,15	15	19	47	100	66	1386	7 %	9,2	8,8	16	0,13	23	5	-1	23
15000	2,0	1,25	3,15	16	20	49	100	76	1556	6 %	9,6	9,2	16	0,13	25	4	-1	23
20000	2,0	1,25	3,15	17	21	54	100	99	1898	5 %	11	10	16	0,12	27	3	-1	23

- V – room volume in m^3
- T – reverberation time in s
- W/H – width to height ratio
- L/H – length to height ratio
- H, W, L – height, width, length
- V/(TN) – volume requirement per musician at reverb time T
- N – ensemble size, number of instruments
- Na – audience number
- Sr - residual floor area, i.e. percentage of floor area not occupied by audience or performers
- V/Na – volume per audience member, regulated by requirement value 6-12 by NBI
- V/Nt – volume per person (performers+listeners) in the room
- A/N – absorption area per musician
- T/H – reverberation time per room height
- Rnom – nominal source to receiver distance, i.e. distance between stage center and center of audience area

- G – sound strength, i.e. natural gain of the room, calculated from T, V and Rnom, by Barron Revised Theory
- C80 – clarity, i.e. level balance between early energy and late energy (arriving >80ms after direct sound)
- L(N) – sound level from N instruments, in dB rel free field level from average instrument at 10m distance

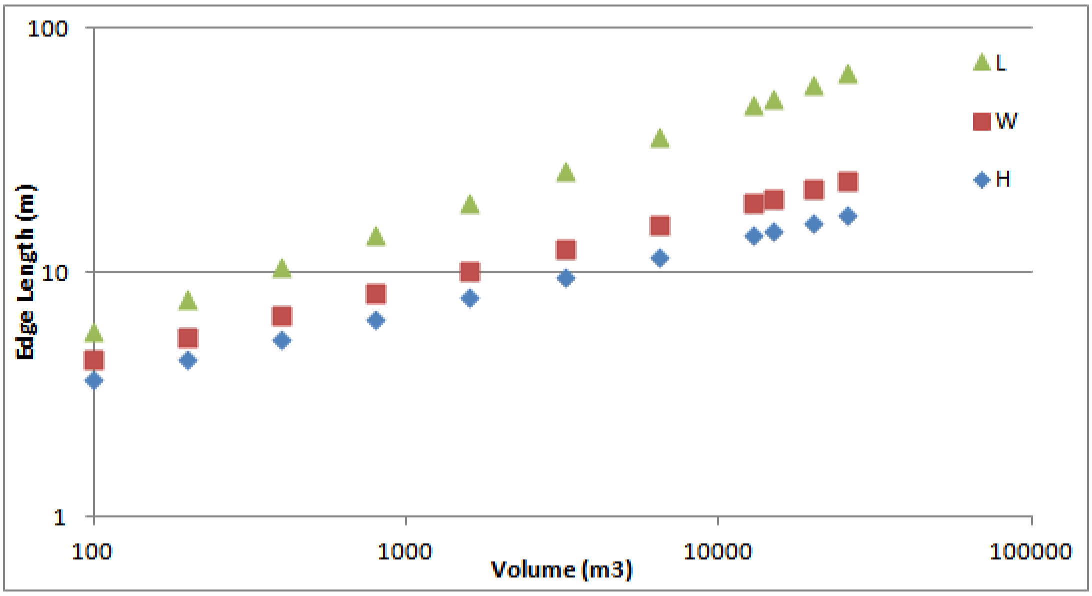

Figure 3 Smoothed room proportions for rectangular halls, in terms of Height:Width:Length (H,W,L), as a function of room volume V(m^3) based on (NBI 527.300, Figure 1.

4 Discussion of critical parameters related to music style and ensemble size

4.1 Reverberation time

"It's all about reverberation time" AND "Reverberation time is not all that matters"

NS 8175 expresses almost all room acoustical requirements in terms of specific limits for reverberation time for specific types of rooms (types are defined by their intended use). However, an important remark is made: "Reverberation time alone is not a sufficiently describing property".

Reverberation time, in terms of early decay time EDT, is found to be governing the perceived Listener's Reverberance, according to ISO 3382. Different styles of music require different kind of reverberation. If reverberation time varies while the level of reverberant sound is kept constant[2], a shorter reverberation time would be preferred for information-intensive parts, i.e. music parts with more rhythmical or tonal information per unit time, e.g. higher tempi. On the other hand, if reverberation time is kept constant and the level is varied, the lower reverberant levels would be preferred for the more information-intensive music parts.

For example, among sound engineers it would be a common experience that reverb times around 2.0s in a jazz/pop/rock recording, or in a live concert venue PA mix, could be just fine if the reverb is kept at a sufficiently low level, i.e. the direct-to-reverberant balance is positive with good margin. The resulting audio image would be of adequate clarity in an ambient environment, supporting the impression of musician and listener being enveloped by a large volume. In contrast, the same music played with the same reverb time in a small room, or mixed with a high reverb level, would be just muddy. Symphonic music is a different story, since it has evolved in environments were direct-to-reverberant balance is low, even below zero. This is the only possible way to reach out to two thousand people by means of passive

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[2] Varying T, while reverberant intensity (which is proportional to 1/A) is constant, can be found in two rooms where ceiling heights is the only difference, and a sound absorbing ceiling dominates the absorption area A, according to Sabine's Formula T=0.16·V/A

acoustics. However, care must be taken to provide an initial time-delay gap (ITDG)[3] of 20-30ms between arrival of direct sound and the onset of reverberant sound. In practice the ITDG is not an acoustic void, but levels of reflections should be kept down.

In large concert halls, reverberation times of about 2.0s have been found to be proper for classical works most commonly played by symphony orchestras. However, this does not directly imply that 2.0s would be preferable in performance spaces that are very different from the common large concert hall, e.g. in a much smaller or a much larger space, or in a space having a completely different geometry.

4.2 Natural gain G of the room

Another important physical quantity, namely the natural sound gain of a room, is also affected by reverberation time. However, an even greater impact on acoustic gain can be made by room volume, or the ratio of the two, T/V. [4]

According to Barron Revised Theory [4], the room acoustical strength[5] G is largely governed by 10·lg(T/V) and by the attenuation 1.8/T dB per 10m increased source-receiver distance, where T is the reverberation time and V is the volume of the room. If reverberation time is reduced from T=2.0s to T=1.5s (-25%) in one and the same room, the change in G would be -2dB at 20m distance from a source.

On the other hand, if we moved from one hall of V=2000m^3 to a similarly shaped hall of V=16000m^3, both having T=2.0s, the change in G would be -9dB at 20m. The scale ratio of the two halls is 1:2, and if the source receiver distance is up-scaled too, we would find that in the back region of the halls, the difference in natural level gain would be all of 10dB if reverberation time is 2.0s in both. One and the same music performed by one and the same performer would be heard with 10dB difference at the back of those two halls. In order to keep the same sound level at the back of the two halls, the music ensemble in the large hall would need to be 10 times larger than the ensemble producing a preferred sound level in the small hall. Even a small 25% change in metric scale corresponds with an ensemble scaling factor of 2.2 if sound level at the back is supposed to be kept equal.

4.3 Enormous variation in volume

In the variety of music rooms, from small practice rooms to big concert halls, the variation in volume is quite enormous. It is not possible to control loudness without proper combinations of reverberation time T, volume V and ensemble size N (number of musicians). Keeping one of the three constant would lead to unacceptable or impractical variation in the two others. However, one should not consider these constraints as compromises to music and music acoustics. Music styles and their proper acoustical environments have evolved through mutual influence and by the laws of selection seen in life and nature elsewhere. One should e.g. not be surprised to find that the T and V values found to be optimum for chamber music are the values found in the very chamber halls where this music evolved some centuries ago.

4.4 Reverberance in the general case (the big concert hall is a special case)

Not only are the two perception aspects Reverberance and Sound Strength inter-connected by the reverberation time – reverberance may not in general be separable from sound strength at all. The separation into the apparently independent aspects Reverberance and Sound Strength may only be valid in the large concert hall case, in which T, EDT, V, G and ensemble size exhibits relatively little variation throughout the preferred halls. One consequence is that EDT is a critical measure of reverberance for listeners in large concert halls, where the value should be close to 2.0s. In smaller performance volumes, preferred reverberance could be perceived at far shorter values. Close to the source, EDT will approach zero in any concert hall, obviously without the sense of reverberance disappearing. Indeed, in ISO 3382, variation in performers perceived reverberance is related to variation in the late reflected energy level, with the suggested measure $ST_{,late}$. One can achieve the same value for $ST_{,late}$ in different ways, e.g. with a shorter and stronger reverb, or a longer and weaker reverb. This means that the performers perceived reverberance in ISO 3382 is not uniquely described by any common decay parameter.

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[3] Though ITDG was originally suggested by Beranek preferably to be about 25ms or less, it appears to be preferable that ITDG is 20ms or more, increasingly with distance from the source.

[4] According to Sabines formula, the absorption area is proportional to V/T, and since the reverberant intensity is inversely proportional to absorption area, intensity is proportional to T/V

[5] Sound Strength G (dB) is the natural amplification of the room, defined by the sound level from a source that would produce a level of 0dB at 10m distance in free field, e.g. in practically anechoic conditions

If the ensemble size is N, then the total average sound level at a receiving point where gain equals G, is $L(G,N) = L_{w,0} + 10 \cdot lg(N) + G$, where $L_{w,0}$ is the free-field level at 10m distance from the average instrument, averaged over time and repertoire. In the case of music for symphony orchestras of today, $L_{w,0}$ and N are properties of the musical piece due to the orchestration chosen by the composer in order to create the intended expression. For a given piece of music, the proper listening level is determined by G alone. Symphonic music, symphony orchestras and symphony halls, with their characteristic properties $L_{w,0}$, N, and G, have evolved together.

4.5 The importance of ensemble size

Since the field of music room acoustics is dominated by concert halls for symphonic music, where G is the only physical property affecting the listening level, the significance of ensemble size N in general music acoustics tends to be under-communicated or even forgotten.

Ensemble size seems to be very important when developing acoustic guidelines that are supposed to be valid for rooms of varying size.

In order to control listeners' loudness consistently throughout large variation of music room size, according to the discussion in this paper, the Nominal Ensemble Size is defined:

$$N = V/(100 \cdot T)$$

At the ears of performers, the loudness is naturally higher than for listeners. Thus it is suggested that for practice rooms and rehearsal studios, the proper ensemble size lie somewhere in the region $N=V/(80 \cdot T)$ for large rehearsal studios and $N=V/(20 \cdot T)$ in small practice rooms.[6] The volume-per-instrument coefficient $V/(N \cdot T)$ for practice rooms should be established as a part of the work towards a new standard for music rooms. As a part of this, ensemble loudness levels on stages of performance rooms should be studied, in order to achieve consistency in loudness for musicians in the practice case and in the performance case.

The importance of introducing the Nominal Ensemble Size above and in section 3 is emphasised and explained by the Pyramid of Acoustic Needs in music rooms, see section 5.

4.6 Ensemble Acoustics vs Soloist Acoustics

Ensemble acoustics and acoustics for solo play is not generally the same. Acousticians judging every hall by singing, shouting, clapping their hands, or assessing impulse response measurements, should keep in mind that they actually judge the acoustic conditions for a solo musical performer. To judge ensemble performer conditions, impulse responses must be analysed with experience or by methods taking ensemble acoustics into account.

4.7 Running reverberation and Griesinger's results

Based on listening tests with trials of reverberant sound of varying combinations of decay time and level, Griesinger [5] found that certain combinations of decay times and levels tended to be perceived as equally reverberant. For example, longer decay time combined with lower reverberant level could be judged equal to a shorter decay time combined with higher reverberant level. In the case of solo play, perceived reverberance seemed to be judged equal whenever the energy balance between the intervals 0-160ms and 160-320ms of the impulse response was equal. He termed this energy balance the Running Reverberation, RR160, Eq (1).

$$RR160 = \frac{\int_{160ms}^{320ms} p(t)^2 \, dt}{\int_{0}^{160ms} p(t)^2 \, dt} \tag{1}$$

In the cases of quartet or orchestral music, Griesinger found that RR160 did not predict equal reverb particularly well. He continued the experiments and found that equal reverb was perceived when backward integrated impulse response curves crossed at about 350ms, Figure 1.

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[6] Interestingly, the expression $N=V/(20 \cdot T)$ happens to coincide with Room Acoustic Capacity suggested by Rindel in order to control Lombard Effect in canteens and restaurants.

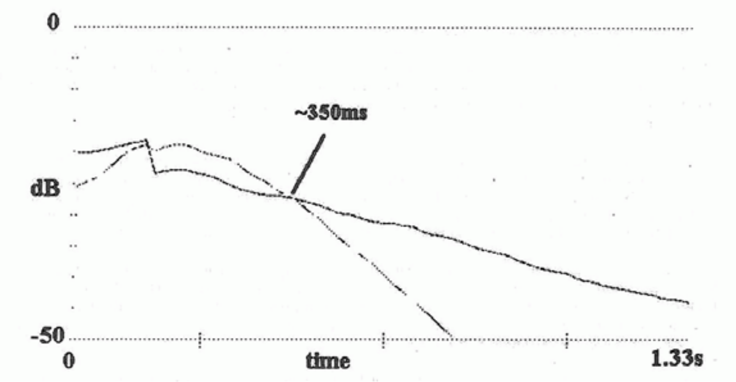

Figure 4 Equal reverb curves, orchestral music [5]

Given the levels *S(t)* of the Schroeder Curve as a function of time *t*, Griesinger defined the running reverberation RR(orchestral) in order to predict equal reverb perceived in orchestral music, Eq (2).

$$RR(orchestral) = \frac{60 \cdot 350ms}{\left[S(0) - S(350ms)\right] \cdot 1000ms/s} \tag{2}$$

In his paper, Griesinger reminds of the fact that EDT in current standards is not uniquely determined, since its calculation depends on sampling rate. EDT was originally designed to describe the time associated with decay from level S(0)=0dB to level S(T/6)=-10dB on the Schroeder Curve, and thereby to some degree describing running reverberation. However, with the current standards, EDT is instead the best fit line to the Schroeder curve segment between 0 and -10dB, putting less weight on the essential first drop from level S(0), in addition to randomness introduced by dependency on sampling rate in the basis for computing the linear regression. This author adds to the comments, that at short distance from the source, e.g. at performers distance from own instrument or colleague instruments, EDT approaches zero, making EDT unable to describe performers reverberance, neither in solo play nor in ensemble play.

A remarkable perception effect reported by Griesinger is that direct sound and reverb sound from a train of tone bursts are be perceived a fluctuating foreground of notes on a continuous reverberant background. This is another example of reverberance having an aspect very different from the aspect of decay, which only can be heard when music stops. Running reverberation is the aspect of reverberant continuity.

4.8 Choice of objective quantity to describe subjective Reverberance in general

It is advised to consider using expressions for running reverberation, in some form, when choosing parameters to describe the perception of Reverberance in the great variety of music room size. Observation tends to indicate that while EDT describes Reverberance in the large concert halls, it does not necessarily do so in music rooms in general. Expressions for running reverberation suggested by Griesinger above are interesting examples in this work.

4.9 Other aspects and their interrelation

Other aspects, apart from Loudness and Reverberance, must be addressed in an order according to the hierarchy of acoustic needs in music, see section 5.1. All aspects have to be approached with general relevance and validity for music rooms, not exclusively for big concert halls, following the discussion above, e.g. sections 4.3 and 4.4.

4.9.1 Reverberance

Reverberance is the temporal aspect of late (arriving at least 80ms after direct sound) reverberant sound

4.9.2 Envelopment

Envelopment is the spatial aspect of late reverberant sound, currently described by late G, alternatively by the lack of inter-aural-correlation of 1-IACC, where IACC is the inter-aural cross-correlation coefficient.

4.9.3 Apparent Source Width (ASW)

Apparent Source Width is the lateral-spatial aspect of early lateral reflected energy.

4.9.4 Articulation

Music is written and performed with notes of varying duration and amplitude modulation (legato, staccato, etc.) forming what we recognise as musical articulation. The amount of early reflected energy describes the degree to which the acoustics of a supports musical articulation.

4.9.5 Tonality, sonority and timbre

Musical notes also define tonal aspects like pitch, melody, sonority, harmony, timbre. Each of these perception aspects correspond to physical quantities in the frequency domain: Tones corresponds to periodic vibrations, pitch to the inverse of period, and timbre to the frequency spectrum. All tonal aspects require more some duration of the sound, and all reflected sound (reverberant energy) contributes to lengthen the duration, thus strengthening the aspects of tonality, such as pitch, melody, sonority, harmony and timbre. However, reflections arriving in the 0-20ms interval after direct sound, is considered detrimental, since these very early reflections most often bring unwanted coloration effects, e.g. like comb-filtering.

The total amount of reflected energy describes the room's ability to support the tonal aspects of music, e.g. the ability to create the common impression that the room 'rings', 'resonates' and 'sings along' with the music being played in it. Such qualities are often considered favourable.

4.9.6 Articulation-to-tonality balance

The ratio of early reflected energy to total reflected energy, determines the balance between the room's support of articulation and the room's support of tonal aspects. Several of the established clarity parameters in room acoustics describes the balance between early energy and other energy-intervals of reflected sound. However, none of them directly describes the ratio in question.

4.9.7 Localisation, pitch detection and ITDG

Griesinger [6] has pointed at the importance of providing for the direct sound to be sufficiently audible, in particular the balance between direct sound and early reflected energy. Reflected energy arriving before 100ms tends to reduce our ability for source localization and perception of pitch, thereby reducing the subjective experience of clarity, intimacy and engagement by the music being played. The earliest reflections (5-30ms after direct sound) have the strongest negative effect in this respect. Griesinger have suggested the LOC as a measure for the predicted ability to localises source and detect pitch (localization and pitch detection is considered to aspects of the same perceptive effect). This author has arrived at a way to provide sufficient LOC by requirements to the ratio of direct sound to early reflective sound, combined with sufficient initial time-delay gap (ITDG) between direct sound and. In many cases, an ITDG of around 20ms or more is required, and required ITDG typically increases with increasing source to receiver distance.

4.9.8 Performers feedback

Musicians are used to adapt to the room acoustical response. If they are able to hear how their music sounds in the same room where listeners are too, they would inevitably try to create the proper tonal quality there. For this to happen there must be good acoustical coupling between stage and auditorium. We need to identify a quantity which varies very little from stage to auditorium, and among the currently common parameters, the best candidate is the late reflected energy, $G_{,late}$. Music will of course always sound differently on stage compared to at listeners' ears, but this is due to the fact that direct sound will dominate more at shorter distance to the musical instruments. In the late energy G_{late} , musicians have a running feedback of tonal aspects at listeners' ears. Late energy is also currently the quantity ST_{late} associated with the aspect 'Performers Reverberance' in ISO 3382. These parameters are promising measures for acoustical coupling between stage and auditorium. However, in order to assess the total sound level of the feedback, ensemble size must be taken into account. In music rooms of varying size the quantities $G_{late} + 10 \cdot \lg N$ and $ST_{late} + 10 \cdot \lg N$ can describe the feedback of listeners' tonal aspects, see 4.8.5.

4.9.9 Aspects, quantities, domains and interrelations

An attempt to see interrelations of the many different aspects, physical quantities and domains is presented in Table 1.

Table 2: An attempt to see interrelations of the many different aspects, physical quantities and domains.

	Temporal domain (time)	Tonal domain (frequency)	Spatial domain (directions)
0 ms Direct Sound	Temporal que	Pitch detection	Localisation
0-20ms initial reflections Strength, Gain G_{early}	Not separable from visible source; May substitute invisible source; Masker of direct sound; ITDG ITDG>20ms perceived as “note is separate from reverb”	Coloration effects on visible sources; ITDG-related Combfilter bandwidth $\Delta F \approx 1/ITDG$; $\Delta F < 50Hz$ if ITDG>20ms	Counteracts source localisation, source separation, pitch detection; ITDG>20ms perceived as “source localized, separate, contained by room”
20-80ms early reflections Strength, Gain G_{early}	Articulation, separation and expression of musical notes; Echo if too strong	Tonality, sonority, harmony, timbre, ‘singing room’	Apparent Source Width (lateral reflections); False localisation if too strong
>80 ms late reflections Strength, Gain G_{late}	Reverberance; Temporal continuity of music; Articulation loss if too strong; Echo if uneven	Musician’s feedback about ensemble’s tonality at listener’s ears; Ease of intonation. Tonality, sonority, harmony, timbre, ‘singing room’	Envelopment, listener’s impression of being enveloped in a room together with musical source; Spatial continuity

4.10 Reinforced music – room acoustics for PA

Acceptable tolerances of T30 in halls for amplified music of varying volume have been presented by Adelman-Larsen [10].

Amplified music, i.e. music reinforced with a PA system, almost exclusively includes a drum set which, together with the natural gain G of the room, defines the lowest possible loudness level at listeners’ ears. In order to control the sound quality of the drums, the reinforced gain needs to exceed the unreinforced level preferably by at least 10dB. In practice, this results in high reverberant sound level from the PA system also on stage. Now, in order to control listening quality at performers’ ears, monitor speakers will have to play sufficiently loud to exceed this reverberant PA sound preferably at least by 10dB. In smaller rooms, and live rooms where natural G is high, this often results in a vicious circle, where musicians request higher monitor levels, again resulting in the need for the sound engineer to raise the PA speaker level again. To prevent this, one can formulate requirements for the minimum achievable level balance between sound from PA speakers and sound from monitor speakers. Preferably, this balance should be a) at least 10dB in favour of monitors, measured at musicians’ ears, and b) at least 10dB in favour of PA speakers at listeners’ ears. In order to maintain musicians feeling of contact with the audience, one should not make efforts to aim at much higher level balance than the 10dB. Excessive acoustical decoupling between stage and house is generally not preferred. However, in larger venues, the balance will inevitably be higher.

4.11 Requirements consistency

We need to see all spaces used for music, spaces containing practicing or performing musicians, as a whole, in order to arrive at requirements that are consistent throughout practice rooms, teaching studios, smaller or larger rehearsal rooms, stage, podium, orchestra pit, auditorium. Not necessarily equal requirements, but still consistent throughout.

5 Acoustical Hierarchy of Needs (pyramid of acoustical needs)

As noted above, the field of music acoustics has been dominated by concert hall acoustics, perhaps with the exception of practice room acoustics, and it has been much concerned with perfection. However, in the great span of music practice, from basic education, practice, via amateur playing, to higher education and professional music performance, the acoustical needs has a correspondingly wide span. In our work towards a standard for music room acoustics in general, we need to establish the differentiated needs in the variety of music practice mentioned before. As an aid in this respect, the Acoustical Hierarchy of Needs, or the Pyramid of Acoustical Needs, is introduced.

Maslow's hierarchy of needs is commonly referred to in many professions. It basically says that long before an individual demands perfection, the individual will demand basic needs. The basic needs are physiological needs like air to breathe and absence of life immediate threats like too cold or to hot temperature. When these basic needs are satisfied, but not before, the needs for water and food will come up. When no longer thirsty or hungry, new needs will come up, but not before, and so on. As an illustration the new, less basic, needs are put on top of the basic needs, like building blocks. Higher up we will find social needs and need for love, and the very top is often referred to as self realization. All these blocks can form a pyramid, often referred to as Maslow's Pyramid.

5.1 Hierarchy of needs – From the basic needs to the need for perfection

In acoustics, we can easily arrange a hierarchy of needs similar to the Maslow Pyramid. In an attempt to make list with the more basic needs mentioned first, the following describes the pyramid upside-down. A summary is illustrated in Figure 4:

- Protection from hearing damage (run away!)
- Protection from painful sound (hold your ears, turn down the amps, use ear plugs)
- Protection from long term noise effects, like psycho-somatic stress reactions (sufficient absorption)
- Absence of noise that blocks important information
- Absence of noise that makes communication between musicians difficult, including too much reflected sound
- Absence of Lombard-effect or other vicious cycles due to lack of acoustic absorption per source
- Sufficient loudness for listeners in order to hear music
- Controlled loudness for performers (without need for air plugs due to excess reverberant sound)
- Absence of echoes, comb-filters, prominent modes, false localisation, or other distortion effects
- Sufficient clarity, i.e. not muddy sound due to excess reverberant sound
- Localisation[7] and pitch discrimination of instruments, sufficient direct-to-reverb balance
- Sufficient spectrum balance, not compromising balance between instruments
- Optimum needs, i.e. more than just sufficient, like in "not too little, not too much"
    - Optimum reverberance, a sense of temporal continuity, yet not compromising articulation
    - Optimum loudness for full music impression, yet no compromising spectral masking
    - Optimum clarity, ensemble effect, harmonic effect, yet not compromising tone (pitch) separation
    - Optimum apparent source width, broad enough audio image, yet not false lateral localisation
    - Optimum envelopment, a sense of being in the same room as the source, yet source is localisable
    - Optimum bass response, e.g. not weaker or shorter reverb toward lower frequencies
- Acoustical perfection, all possible acoustical demands are satisfied

An obvious consequence of the Pyramid of Acoustic Needs is that it makes no sense to bring in requirements for Reverberance, before Loudness is under control. This fact emphasises the importance of introducing the nominal ensemble size requirement suggested in this paper, see sections 3 and 4.5.

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[7] In light of evolution, localization and pitch detection has been a matter of survival

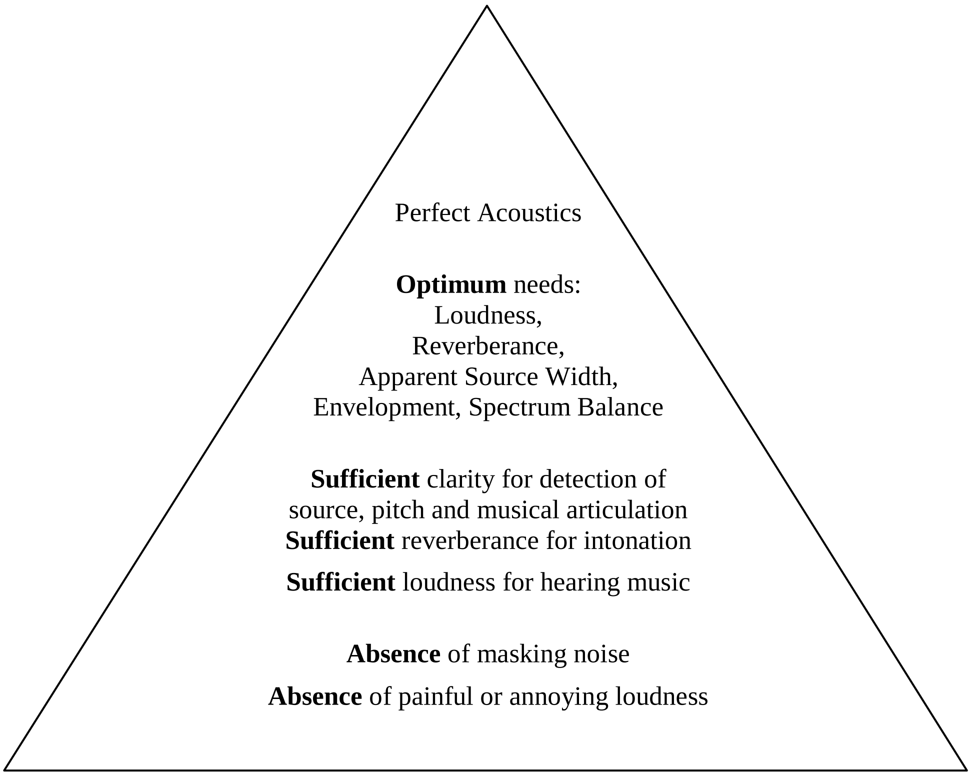

Figure 5 Pyramid of acoustical needs, relevant for music rooms

5.2 Examples of how the Pyramid works

Example 1: In first grade schools, acoustics of the music room is all about loudness control, in the sense of limiting the reverberant intensity. Before loudness is under control, few teachers and pupils will start complaining about lack of reverberance due to the common low room height in the one-storey rooms. In higher grades, and in higher education, teachers and students will start demanding reverberance and other higher needs in the pyramid in Figure 4. In practice this will call for higher practice rooms and even higher group rehearsal rooms, requiring rooms ranging over several storeys. In general, the number of different aspects needed to be satisfied, increase upwards in the pyramid.

Example 2: Focusing on how the aspect of loudness could develop up through the pyramid: At the bottom of the pyramid, one might require $L_p < 110$dB. Ear protection is the only demand. But then we at least want to hear the music, so we require at least $60 < L_p < 110$dB. Still not very demanding. Towards the top of the pyramid, the need for optimum might increase by reducing the level tolerance via average levels within 75dB $< L_p <$ 95dB, arriving at e.g. 82dB $< L_p <$ 88dB. Needs related to a single aspect tend to become more specific higher up in the pyramid.

6 Conclusions

An enormous variety of music room sizes appears to be the main challenge in the work towards a new standard for music rooms. The field of music room acoustics has been dominated by large the concert hall case, which is to be considered a special case, and whose parameters are not proven to have general relevance valid for the great variety of music rooms. In particular, it is not fruitful to use parameter values recommended for big concert halls as ideals for the general music room.

It is advised to consider approaching some form of quantity for running reverberation when choosing parameters to describe the perception of Reverberance in the great variety of music room size. Observation tends to indicate that while EDT describes Reverberance in the large concert halls, it does not necessarily do so in music rooms in general.

A requirement for volume related to ensemble size in music spaces, i.e. the Nominal Ensemble Size $N = V/(100 \cdot T)$, is suggested as an addition to existing Norwegian standards. It is concluded that the addition provides consistent loudness control throughout the variety of music room volume. In further work a similar requirement for music practice rooms is to be established, supposedly in the region $V/(80\cdot T)$ and $V/(20\cdot T)$.

The Pyramid of Acoustic Needs is suggested, as an aid for development of music room requirements. A consequence of the Pyramid is that it makes no sense to bring in requirements for Reverberance, Clarity, Envelopment, Apparent Source Width, etc, before Loudness is under control. This fact emphasises the importance of introducing the nominal ensemble size requirement suggested in this paper.

References

[1] Standard Norge, NS 8175:2008, Acoustic conditions in buildings, Sound classification of various types of buildings, Oslo, 2008.

[2] SINTEF Byggforsk (National Building Research Institute), Byggdetaljblad 527.300 Romakustikk. Guidelines for room acoustics in rooms for speech, music and sound reproduction, by Jens Holger Rindel, Oslo 1998.

[3] Norsk Musikkråd (Norwegian Music Council), Normer og Anbefalinger (Standards and Recommendations), Oslo 2010.

[4] M. Barron, Auditorium Acoustics and Architectural Design (E & FN Spon, London, 1993).

[5] D Griesinger, How Loud is My Reverberation, http://www.akutek.info/Papers/DG_How_Loud.pdf

[6] D Griesinger, The audibility of direct sound as a key to measuring the clarity of speech and music, 162nd ASA-meeting, San Diego 2011, http://www.akutek.info/Papers/DG_Audibility_Direct_Sound.pdf

[7] T Halmrast, Sound coloration from (very) early reflections, ASA, Acoustical Society of America, Chicago 4th june 2001, http://www.akutek.info/Papers/TH_Coloration2001.pdf

[8] T Halmrast, Coloration due to reflections - Further investigations, ICA07, Madrid 2007, http://www.akutek.info/Papers/TH_Coloration2007

[9] A Buen, Early Design Criteria for Small Multipurpose Cultural Houses, BNAM 2010, Bergen 2010, http://www.akutek.info/Papers/AB_EarlyDesignCriteriaSmallHalls.pdf

[10] N Adelman-Larsen, On a new, variable broadband absorption product and acceptable tolerances of T30 in halls for amplified music, 162nd ASA-meeting, San Diego 2011, http://www.akutek.info/Papers/NAL_ASA_2011.pdf