Chapter 5
Recommended Acoustics for Pop and Rock Music

As pop and rock evolved during the 1950s, '60s, and '70s dedicated venues for this music were built. Buildings formerly used for other purposes such as cinema or factories found new life accommodating live, amplified dance music, from bars and clubs for a few hundred people to actual music halls for more than a thousand people at the other end of the scale. And since the 1990's there has been an improved focus on the acoustics of sports arenas, that are used to house some of the most popular pop stars, with regards to amplified music.

Knowledge gathered from a large number of halls indicates that a fair share of acoustic consultants have been aware of what kind of acoustics is needed for amplified music. But other halls have not had the same luck and there have been a few typical misconceptions and pitfalls when designing for this purpose. Despite good efforts, the recommendations have not been complete regarding acoustics for amplified music. Some authors, however, briefly include the topic. For instance. the late, great architect Russell Johnson is referred to by Ahnert and Steffen in their book, *Sound Reinforcement Engineering* 1999, to recommend a reverberation time $RT_{(500\text{-}1k)}$ of 0.8–1.2 s in halls for dance bands. But nothing is mentioned as to which hall volumes these numbers correspond or to recommended RT at other than mid-frequencies. Barron mentions in *Auditorium Acoustics and Architectural Design* 1993, that a T_{30} below 1 s is recommended.

Some textbooks on room acoustics recommend that "halls for music" have an increase of reverberation time at frequencies below 250 Hz (despite the fact that many of the very best rated halls for symphonic music don't show this trait without an audience). Surely, this brings "warmth" to the sound. But this is only true for (unamplified) classical music. For amplified pop/rock music, as shown in this chapter, it is enemy number one! At unamplified music events the acoustics of a hall, together with the sound level produced by the ensemble, are solely responsible for the total sound level in the hall. And with some help from a longer reverberation at low frequencies, the bass sound is acoustically amplified and the overall sound thereby perceived "warmer". At amplified music concerts, however, producing enough level for the audience is obtained just by turning knobs on the

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instrument, the amplifier on stage, monitors, and of course importantly, by pushing faders and turning gain knobs on the FOH mixing console, adjusting the sound level provided by the PA system. In fact possible level differences because of uneven frequency response are equalized in numerous places as mentioned earlier: many musicians will automatically try to adjust their levels, and in smaller rooms some will equalize their instrument or amplifier to fit the response of the hall; both the PA system and often also the monitor system will comprise graphic equalizers to even out level differences resulting from the sum of the possible acoustic amplification of the hall and electroacoustic amplification of the PA system. And finally the sound engineer will decide both on faders and equalizers for each channel as well as on possible outboard devices such as compressors, the decided level of an instrument, and how it blends in the complete mix.

In this way, in halls for amplified music, the effect of reverberation time on sound level is not in focus. Moreover, delay speakers can be applied to enhance levels farther back in the hall, should it be inadequate. But as shown earlier, a low reverberation time gives a long critical distance and thus few members of the audience experiencing an overall reverberant sound. So is it not as simple as suggesting that for the greatest possible share of the audience to get "good," defined, direct sound, then as short a reverberation time as possible should be chosen. Are the "outdoor conditions" with no reflections what we need to bring inside the hall? The answer is a definite NO. Close to anechoic (little reflections) conditions would be chosen from such a strictly logical reasoning and chapters on critical distance found in, for instance, the *Sound Reinforcement Handbook* by Davis and Jones 1990, can surely leave the reader believing this. Some consultants have chosen almost anechoic acoustics for amplified music halls assuming that the only focus point was freeing the audience from undefined reverberant sound. And that hypothesis has in some cases been taken to the extreme sometimes even without enough focus on absorbing low frequencies. But as shown later demonstrate, this is not a correct path to pursue. In this chapter, we will see what values of reverberation time are recommended for a given hall volume; it must be relatively short, but not too short, and within limits it can vary with frequency.

The Basis of the Recommendations

In 2005 a study regarding recommended acoustics for pop and rock music was conducted in Denmark. To this day it seems to be the only proper research ever made for this purpose. The results from the survey were unambiguous, therefore recommendations have been made on this basis and they form the platform of this book. The author of those research papers and of this very book served 15 years in the music industry as a jazz and rock drummer, and played more than 1,200 concerts. A large share of those concerts was performances with the same band, playing the same music in the same venues with the same sound system and sound engineer over several years. That experience made the author certain that halls actually leave an acoustic imprint in the memory of at least some musicians and sound engineers. The author had a good network among Danish musicians, sound engineers, and venues. It was therefore a manageable task to conduct an investigation where a number of musicians and sound engineers were asked their opinion about the acoustics in the 20 most commonly used venues in the country. By looking in the venues' calendars from previous years it was determined which bands and musicians had played most often in a large number of the halls. A questionnaire was sent to 50 musicians and 18 sound engineers of whom 25 musicians and 8 sound engineers responded.

In a letter to the musicians and engineers accompanying the questionnaire the test persons were instructed only to fill out the sheets if they felt sure about their responses and to omit the halls they were not very familiar with or for other reasons felt uncertain about judging. The letter to the musicians said:

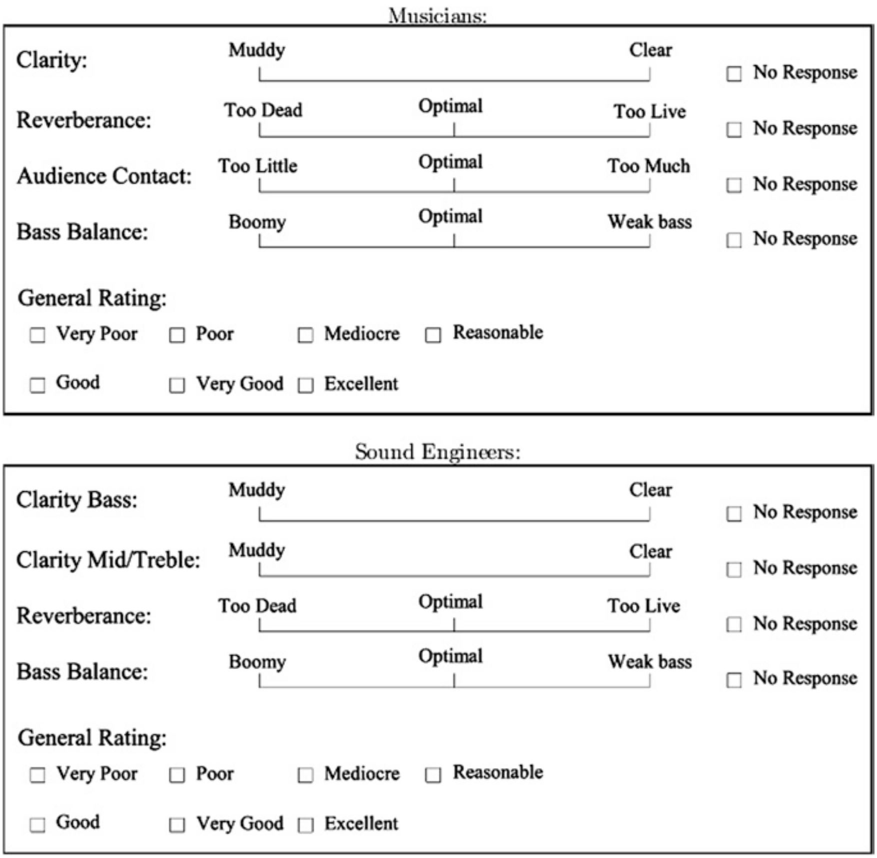
> As a musician, one evaluates venues—consciously or subconsciously—based on factors, such as: how good is the visual contact with the audience, is the temperature appropriate, is the service good etc. In this anonymous survey, the focus is on the acoustics of the venue for the performers. This means: how does the hall respond to the music that is played—judged independently (as far as possible) of the PA-system, the monitor technicians etc.

Then the first page of the survey included questions about what kind of monitors the band uses (in-ear, headphone, stage monitors, other), whether the respondent used to discuss the acoustics of halls with their colleagues (yes/no), how important acoustics are for the respondent (very, somewhat, a little, not important), whether the respondent had chosen not to play in certain halls on the account of the acoustics (yes/no), and whether the respondent found that possible negative effects of the acoustics could be mitigated through the use of in-ear monitors (very, somewhat, a little, no).

Then the respondent was asked to complete a questionnaire for each hall, asking for ratings of the halls on several acoustic aspects. This part of the questionnaire, that had to do with each hall, was based on the questionnaire used by Barron in his 1988 paper, "Subjective Study of British Symphony Concert Halls." Some of the parameters used in Barron's questionnaire were changed to better fit a rock setting. It was expected that the subjective ratings of Clarity, Reverberance, and Bass Balance would be correlated to the objective measures D_{50}, T_{30}, or EDT and BR. Figure 5.1 shows the questionnaires that were sent to musicians and sound engineers, respectively.

The respondents were free to set a mark anywhere on the continuous line. There was an "optimal" mark at the center point of the line for all but the Clarity rating. The positions of the respondents' marks on the line were measured assuming a linear scale and the data were gathered for statistical and correlational analysis in order to investigate how they corresponded with objective measurement data of the 20 halls.

The 20 halls were acoustically measured according to standards (ISO 3382:1997) with an omnidirectional source (dodecahedron). Obtaining the relevant data also in the 63 Hz band was a focus point wherefore an omnidirectional subwoofer was used together with the dodecahedron. For another round of



Musicians:

Clarity: Muddy — Clear ☐ No Response

Reverberance: Too Dead — Optimal — Too Live ☐ No Response

Audience Contact: Too Little — Optimal — Too Much ☐ No Response

Bass Balance: Boomy — Optimal — Weak bass ☐ No Response

General Rating:

☐ Very Poor ☐ Poor ☐ Mediocre ☐ Reasonable

☐ Good ☐ Very Good ☐ Excellent

Sound Engineers:

Clarity Bass: Muddy — Clear ☐ No Response

Clarity Mid/Treble: Muddy — Clear ☐ No Response

Reverberance: Too Dead — Optimal — Too Live ☐ No Response

Bass Balance: Boomy — Optimal — Weak bass ☐ No Response

General Rating:

☐ Very Poor ☐ Poor ☐ Mediocre ☐ Reasonable

☐ Good ☐ Very Good ☐ Excellent

Fig. 5.1 The questionnaires sent to musicians and sound engineers differed slightly

measurements, the PA system of the hall was used as the sound source in conjunction with the exact same microphone positions used for omnisource measurements.

Results of the Interviews

The First Page of the Questionnaire

The results of the study, and a precise description of it, were published in the *Journal of the Acoustical Society of America* in 2010[1] with the help of Dr. Eric R.

[1] "Suitable reverberation times for halls for rock and pop music." *JASA*, 127(1), Jan. 2010, Adelman-Larsen et al.

Thompson and Dr. Anders Gade. As mentioned, about half the people to whom the questionnaire was sent actually answered it. Those who did not return it may have felt unable to answer and may not be as conscious of, or as affected by, the acoustics as those who did. Or there may have been other reasons. Of course, not all halls obtained an equal amount of questionnaire returns, so the statistical certainty for correct ratings is not the same for all halls. Among the 25 musicians who responded there were eight drummers, seven bass players, five guitar players, three keyboard players, and two singers. It is very possible that different instrumental groups prefer somewhat different acoustics. More test people than 25 are needed in order to achieve significant knowledge about this. In any case, the average obtained in this study is relevant because all these instruments are regularly represented on any stage for pop and rock music.

On the question, "How important are the acoustics of a venue to you?" Seven out of eight sound engineers and 17 out of 25 musicians answered "very important," the remaining sound engineer and 7 musicians said that acoustics are "important," and the remaining 1 musician said that acoustics are only "slightly important." Two of the eight sound engineers had considered not playing, and 8 of the 25 musicians said that they had chosen not to play in certain venues because of inadequate acoustics. All sound engineers and all musicians said that they discuss the acoustics of specific halls with colleagues.

Five sound engineers responded that their bands used in-ear monitoring, seven reported using onstage monitors, and one reported using headphones and monitors (note that the respondents could choose more than one monitor type). Fourteen musicians reported using in-ear monitors, 19 used on-stage monitors, and three musicians (all drummers) reported using headphones. On the question of whether in-ear monitors can help mitigate the possible bad effects of a hall's acoustics, four sound engineers and nine musicians responded, "very much," three sound engineers and eight musicians responded, "somewhat," and one sound engineer and three musicians responded, "a little." The remaining five musicians either responded, "don't know" or did not respond. These responses are of importance; the direct sound experienced when using in-ear monitoring certainly to a large degree masks possible unwanted reverberant sound, but only at frequencies above some 250 Hz. The in-ear/closed headphones do not block lower frequency sound that the musicians seem to be able then to hear, both with their ears and from vibrations leading to sound perception by the inner ear through bone and body conduction. Some musicians are capable, in a positive way, to focus on the higher frequency direct sound rather than reverberant, undefined lower frequency sound. In order to try to mask the reverberant low-frequency sound with some direct low frequencies, some musicians, especially bass players, get a vibration-plate to stand on and drummers sometimes invest in a so-called "butt kicker," a vibration transducer that can be mounted on their drum seat. None of the musicians in this survey used those tools.

To the question whether musicians choose not to play in certain halls, there were cases where one member of a band said no, and another said yes. Maybe the one answering yes is involved in the booking process and the other one is not.

Or the first one plays in other bands also with other preferences on this subject. Overall, these results showed that acoustics are certainly important for rock musicians and sound engineers although in-ear monitoring lowers the importance to some extent for musicians.

PA System Versus Omnidirectional Source Measurements

In the Fig. 5.2 definition, D_{50} is shown as a function of frequency as an average across all halls, for both omnisource and PA measurements and both with measurements in the audience area and on stage. It is seen that the highest definition is achieved with the omnisource on stage somewhat more defined than the PA sound in the audience area. Of course the microphone positions farthest away from the PA speakers often account for a lower D_{50} than those close to the speakers where the direct sound is usually louder relative to the reverberant, not so defined, sound. In most of these halls those more distant measurement positions pull the curve downwards. Some speaker configurations seek, as earlier mentioned, to compensate for this effect. On stage the distance cannot get as long as in the audience area but on the other hand the PA speakers are more directive than the omnispeaker at mid–high frequencies. The effect of this is seen on the curve of the omnisource measured in the audience area.

Not surprisingly the least defined of these groups of sound is encountered on stage as a result of the reflected higher frequency sound emitted by the PA speakers. If that PA sound becomes too loud on stage the musicians have no choice but to turn up their monitoring. And if the monitors are open monitors on stage (and not in-ear monitoring) they may get so loud that the sound engineer operating the PA system feels obligated to turn up the PA level because the loud monitor level masks the correct mix in the PA system, even at the sound engineer's position among the audience. This is a well-known phenomenon, an evil spiral, leaving both musicians and audience with too-loud sound levels and worse sound quality because of monitor sound leakage into open microphones on stage, as well as possible inappropriate monitor sound in the audience. Furthermore, because the low-frequency sound emitted by the PA speakers is omnidirectional the graph shows higher values of D_{50} on stage. Probably the 250 Hz band is just omnidirectional enough to get a high-definition value whereas on stage the 125- and 63 Hz values decrease due to a higher reverberation time at these frequencies in the average hall. The later, low-frequency reflections are, as we show, actually the primary cause for poor acoustics as perceived both by sound engineers and musicians.

Referring to Fig. 3.7, it is a fact that the more sound the PA system shoots onto the walls and ceiling the more the reverberation of the hall is evoked. The recommendations in this book cannot take the effect of the different PA configurations in different halls into account. The ratings in the following section are a grand mean of many responses to many halls, therefore it is believed that the effect of different

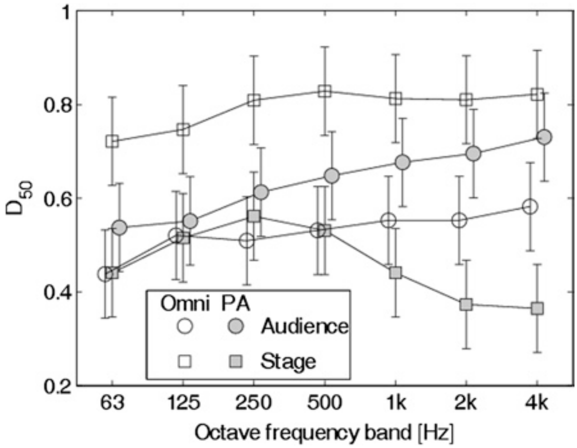


Fig. 5.2 D_{50} as a function of frequency, averaged over 20 halls in the audience area and on stage for both omnidirectional source and PA system

PA systems is somewhat evened out and that the ratings are indeed applicable and shall be employed in conjunction with an appropriately designed PA system.

General Ratings of the Halls

Each musician and sound engineer assigned a general rating to each hall constituted by a number from 1 to 7, where a 1 corresponded to "Excellent" and 7 corresponded to "Very Poor." The mean general rating for each hall was then calculated for the group of musicians and for the sound engineers, and the combined rating was calculated as the mean of the two groups. The ordinal rank of the halls' ratings from 1 (best hall) to 20 (worst hall) for each group and the ordinal rank for each hall are shown in Table 5.1. The halls are sorted by volume in order from smallest to largest, and it is interesting to note that there is no correlation between the size and the overall rating.

Interestingly, the driest hall, Stars, is in the tenth place in the musicians' ratings category but is the favorite of the sound engineers, which moves it to the fourth best rating overall. Stars was also rated the driest on the "Reverberance" scale (the only hall rated by the musicians as "too dry"). So even though the group of sound engineers in this survey liked the recording studio quality of the hall, it is a good example that a hall can be too dry for musicians. Later interviews with other sound engineers have revealed that another group of sound engineers actually prefers acoustics much like those favored by the musicians. The four lowest-rated halls have a relatively high T_{30} and typically a longer reverberation time at lower frequencies. Viften has an extraordinarily long reverberation time in the 63 Hz octave band (over 3 s) and in the 125 Hz band and much shorter reverberation above 500 Hz (around 1 s) due to banners on the walls. This is also the hall that the sound engineers rated the lowest on "Clarity Bass."

Table 5.1 Overview of the 20 investigated halls that form the basis of the recommendations in this book

Name	Volume (m^3)	Audience capacity	$T_{30,B}$ (s)	$T_{30,M/T}$ (s)	EDT (s)	D_{50} (s)	Bass ratio	General ratings		
								Musicians	Sound engineers	Combined
Rytmeposten	655	300	0.8	0.8	0.3	0.6	1	14	10	11
Lille Vega	785	500	0.5	0.7	0.4	0.7	0.7	1	6	3
Loppen	890	350	0.9	0.8	0.5	0.7	1.2	5	13	9
Skråen	1100	375	1.5	0.8	0.9	0.4	1.8	13	12	13
Paletten	1420	375	1	0.9	0.7	0.7	1	8	8	8
Stars	1440	400	0.6	0.6	0.3	0.8	0.9	10	1	4
Voxhall	1600	500	0.9	0.6	0.5	0.7	1.3	7	5	6
Sønderborghus	1600	420	1.2	1	0.8	0.6	1.3	20	18	19
Musikhuzet	2080	700	1.1	0.9	1.1	0.5	1.2	9	17	12
Godset	2150	700	0.7	0.8	0.5	0.6	0.8	6	4	5
Magasinet	2540	525	1.9	1.3	1.3	0.3	1.4	12	19	18
Pumpehuset	3000	600	1.2	1.1	1	0.6	0.9	16	15	15
Forbrændingen	3050	450	1.1	0.9	0.5	0.8	1.2	19	11	14
Train	3300	900	0.8	1	0.4	0.7	0.9	3	2	2
Slagelse	3800	700	1.8	1.6	1	0.5	1.1	17	20	20
Viften	3950	700	2.6	1.2	1.1	0.6	2	18	14	16
Amager Bio	4500	1000	1.2	1	0.8	0.6	1.1	4	9	7
Torvehallerne	5400	700	1.2	1.5	0.9	0.5	0.8	15	16	17
Store Vega	5800	1430	1.4	1.2	0.7	0.7	1.1	2	3	1
Tobakken	6500	1200	1.5	1	0.8	0.6	1.4	11	7	10

The values of EDT and D_{50} are averages of the octave bands 63–2 kHz. $T_{30,B}$ is averaged from the 63- and 125 Hz bands and $T_{M/T}$ is averaged from 250–2 kHz. The BR is the ratio of the average reverberation time in the 63- and 125 Hz bands to the average reverberation time in the 0.5–2 kHz octave bands

Musicians' Preferences

It is first of all important to note that all musicians' taste regarding acoustics is not the same. There may be, as mentioned, some instrumental groups that want a more reflective hall than other groups, and there certainly is a degree of personal taste involved. The recommendations in this book are a grand mean of instrumental groups and individual preferences. Therefore it is safe to construct venues from these, but it is also almost certain that someone will not fully agree. Also there is some influence stemming from what exact genre within amplified music the hall is to be used for; a Brit-pop band has a different frequency content than an electronic music act.

The survey of 2005 proved among other things that musicians need halls not to be too acoustically dead and not too lively either. Probably the most frustrating for musicians is hearing the music reflected from the audience area loud compared to the earlier reflections from the stage surroundings including their own direct sound and that of the monitors. It gives a distancing sensation; the musician feels detached from his or her own playing and thereby disengaged from the situation. It is often thought that this can be eliminated with the use of monitors, but neither open monitors nor in-ear/closed headphones can sufficiently mask the sound of the hall if it is dominant. There is a need for the early sound being enveloping for the musicians who often move around the stage and this calls for some early reflections from the stage surroundings. This is indicated by halls with an overall quite long reverberation time and their quite bad rating such as Torvehallerne and Sønderborghus. Moreover this was confirmed by some musicians who in the survey, as a comment at the end of the questionnaire, specifically stressed that "the worst thing is a small enclosed stage detached from a large hall."

Some musicians are better to cope with this situation than others. For instance, one of the world's greatest jazz pianists of all time, Keith Jarrett, stopped his concert twice during the first set of his 2011 appearance in Copenhagen and announced that he was unable to play certain tempos as he "did not receive any sound back from the hall." In the intermission a reflective curtain was therefore lowered covering the huge hole in the proscenium of the hall behind the musicians. Not only did Jarrett and his trio play without further disturbances through the second set, just as important, the sound engineer was now able to turn up the PA level considerably for the benefit of the audience, because he did not have to worry any longer that the PA level would mask the direct monitor sound and early reflections on stage. So Jarrett got more of a feeling of the music he and his trio were producing. He was unspecific about what sound he was missing in terms of where the reflections should come from, but two important lessons can be learned from that concert: the monitors on stage consisting of both one monitor on the floor for each of the three musicians and a side-fill system of two loudspeakers at a greater distance from the musicians were not able to deliver enough sound. Early stage-based reflections were what the musicians first and foremost needed to feel good about their playing. Second, they needed a certain idea of what imprint their music had in the audience area, that is, enough late, hall-based reflections from that area to be audible on stage. They like to be able to "hear how the music lands" at the audience because the audience is their primary concern. The louder PA level provided that in the second set; but very, very important were the late reflections not louder than what the earlier reflections from stage surroundings could partially mask. Musicians live for giving audiences a great experience.

Without reflections from the stage area, even with a complete monitor set-up, the musician will not experience a sensation of being enveloped in his and his colleagues' sound. With too much sound coming back from the hall he certainly will feel enveloped in sound but, too-strong late reflections will make the musician feel disengaged from his playing and will tend to affect his timing. Of course musicians experience these defects frequently and they cope with them by being somewhat conscious about the sound and navigate accordingly to get timing correct. But that does not make defects acceptable or recommended. On the contrary, if both stage and hall are too dead, small and natural timing differences between the musicians become very clear which can lead to uncertainty and for them to lose confidence. And ironically, when the confidence is there, there will probably be no timing issues.

So it is seen that, according to musicians, the acoustics on stage mustn't be dead compared to those in the hall, and the acoustics in the hall must be neither too dead nor too lively.

Sound Engineers' Preference

Sound engineers are responsible for the sound during concerts given the equipment and band at hand. The sound engineer is placed in the audience area and therefore has perfect possibilities for knowing what sound impression the audience perceives. It's safe to say that sound engineers are trying to give their audience as good an overall experience as possible. Unless really well prepared for, they have little or no possibility to enhance the acoustics of a hall before a show because this implies quite dramatic changes in large areas of the hall. The sound engineer sees it as her job to create as defined and transparent sound as possible and to add suitable effects such as artificial reverberation into the mix. If the hall does not add much reverberation itself, or rather if the combination of hall and PA system does not add much reverberation, the engineer has quite a lot of freedom in playing with artificial effects.

When the question about acoustics in halls is debated, it seems that sound engineers can roughly be divided into two categories: those who want the hall to give some envelopment, as is the preference of the musicians, and those who like more control over their outboard effects to be added to the mix. The largest share of the group of top sound engineers, who were asked in the above-mentioned survey, had the driest of all halls, Stars, as their favorite. They do admit an element of "selfishness" to this preference; after many difficult concerts in inadequate halls they see a concert in Stars as their “shining hour;” a possibility of having complete control and freedom because no reflections interfere. Later interviews with other, equally acclaimed sound engineers have shown that they don’t want the hall to be completely unresponsive. They too, enjoy being surrounded by sound, just like the musicians and probably also the audiences as long as they can provide a nice transparent mix too. Sound engineers are trained in the fine art of making a great mix. That is a completely different métier than room acoustics.

Many sound engineers like the stage to be quite dead: this prevents sound from instruments and monitor speakers from being reflected to the audience area or to leak into open microphones on stage. In this way they can keep as much unprocessed sound as possible out of the total mix that meets the audience. The stage reflections entering the open microphones on stage are delayed and possibly out-of-phase with the direct signal. These reflections of course harm the total mix. Much in the same way regarding the audience area, a relatively dead hall will make the sound engineer capable of forming a sound experience to his taste on the PA system.

Debate

So here is in fact often a dilemma between what most musicians want and what many sound engineers find recommendable. A dead stage leaves the musicians unable to hear themselves, each other, and the audience sufficiently loudly and with enough envelopment. Moreover it requires from the point of view of the musicians a dead hall, for the stage not to be more dead than the hall, and that they don’t want either. This of course opens the debate about who should decide on what acoustics is appropriate for a venue for pop and rock music. For classical music there is no sound engineer but there is a conductor who often brings valuable insights into play when discussing recommendations for classical music halls.

Evidently the audience plays the key role. They actually buy the tickets that pay for the band and sound engineer. So what does the audience want? The most encountered opinion on this is that the audience wants to experience the fantastic ambience and incredible moods that are often connected with pop and rock concerts. They want to be drawn into a special atmosphere that is made during the concert. The better the musicians feel on stage, and the less they worry, the better their chances of creating a great performance, possibly even unforgettable for themselves and the audience. And remembering that musicians like to hear their music “land” at their audience, it is regarded safe to say that when the musicians are pleased, the audience is pleased too. A musician is not content if her audience is not. And as we saw, musicians too need quite a clear sound, although not overly defined, in order to enter a state of togetherness with their colleagues and the audience who then in return share a common bond with the band and each other. And everybody will praise the sound engineer as well for having participated in creating such an event.

Therefore it is believed to be correct to follow the taste of the musicians which is identical to that of some sound engineers. Other sound engineers may find these conditions on stage as well as in the hall a little too reverberant in order to create the perfect sound they had in mind. These slightly reverberant conditions make their job a little harder if the band sounds harsh or unprofessional, but it must be remembered that there are also other interests in play that benefit the whole event. Many performers have reported their most memorable concerts to have taken place in halls that were not dedicated halls for music. An acoustics signature of such a space leaves them with a good impression, as long as they were able to adapt to the conditions at hand.

Spectral Analysis of Surveyed Data

From all the concerts the author had experienced as a musician he knew that a long reverberation time at low frequencies was particularly disturbing. This is not so peculiar and has been known by some acoustical engineers and other professionals for decades. This is due to different factors: the bass sound is amplified by thousands of watts at pop and rock concerts. By far the biggest share of electric amplification energy is used below 200 Hz and reaches considerable levels as seen in Fig. 3.2. The audience does not absorb much low-frequency sound (Fig. 1.16). Because of a low Q value of bass loudspeakers emitting bass sound the critical distance becomes very short leading to much reverberant bass sound almost everywhere in the venue (Chap. 1, Eq. 1.8). Therefore an overall undefined sound will most often stem from reverberant bass sound that, because of the loud level, will partially mask even the direct higher frequency sound. Only a controlled reverberation time at low frequencies can make up for this.

From this knowledge the average reverberation times of the 10 highest and the 10 lowest rated halls were calculated and presented in the same diagram as a function of the octave band. To eliminate the factor that bigger halls can admit a longer reverberation time, the reverberation time of each hall was divided by its volume. With that normalization the effect of volume was eliminated. The ratings for sound engineers and musicians were for this purpose averaged into one combined rating hoping to find a factor that would be important for both groups of professionals.

The result is seen in Fig. 5.3. In this figure the upper line shows an expression of the average RT of the lowest rated halls for each octave band and the lower line is the average of the best halls. The vertical lines around each point show the statistical confidence levels. The results of the two groups of halls cannot really be differentiated from one another above the 250 Hz octave band. But it also, more notably, means that what actually distinguishes the best from the not-so-well-liked halls is a shorter reverberation time at low frequencies. This is believed to be the most important finding in the survey. Furthermore, inasmuch as the variances do not overlap in the two (or three) lowest octave bands, the diagram shows statistical significance, whereby it constitutes a scientific proof that must be accepted by any

Fig. 5.3 Averaged RT divided by hall volume for the 10 best and the 10 worst rated halls as a function of the octave band

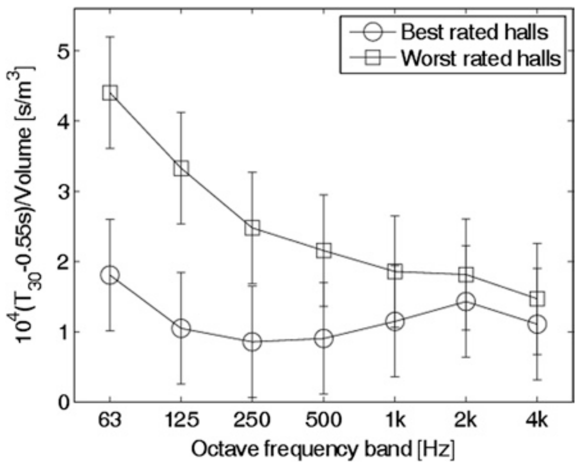
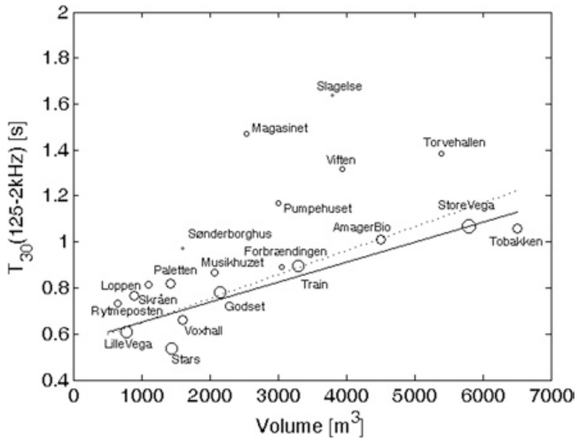


Fig. 5.4 Solid line shows recommended RT for an empty hall at various hall volumes. The dotted line is for the average including the 63 Hz band. The line is linear in the small interval from 1,000–7,000 m^3, but certainly cannot be extrapolated linearly to larger volumes. Applying a logarithmic scale on the *x*-axis over large volumes, recommended RT would approach a straight line



scientist or acoustical consultant. This is one factor that has to be fulfilled in making a recommended hall for pop and rock music. This is the single most important message of this book.

Furthermore, for the best halls the diagram shows a small increase in reverberation time in the 63 Hz band. Of course this cannot per se be taken as a recommendation because it is just a result of the average of the halls at hand and this rise is difficult to avoid. But the increase is an indication that this is acceptable in the 63 Hz octave band. As mentioned, the best halls have a significantly lower RT in both the 63 Hz and the 125 Hz octave bands compared to the worst halls. It therefore is at least hypothetically possible that an increase in just one of them is acceptable. Because of this ambiguity, some other venues with an increase of RT mainly in the 63 Hz band were studied (Figs. 5.4 and 5.5).[2]

[2] "On a new variable absorption product and acceptable tolerances of T_{30} in halls for amplified music;" convention paper, ASA, San Diego, 2011, Adelman-Larsen et al.

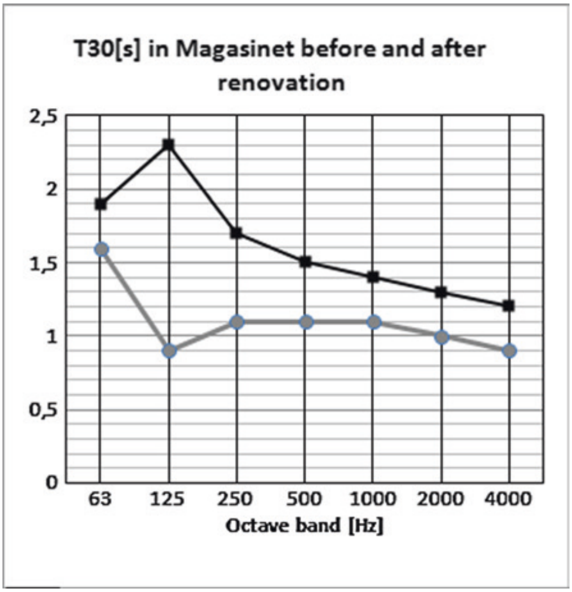


Fig. 5.5 Measurements before (*black*) and after (*grey*) installing tuned membrane absorbers in a hall

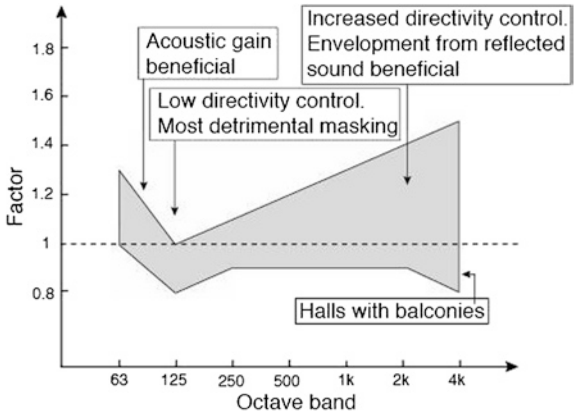


Fig. 5.6 Approximate factors of T_{30} in the octave bands 63–4 kHz. Factor 1 refers to the relevant value in Fig. 5.4

These investigations lead to an understanding that RT in the 63 Hz band can be a factor higher than that of the 125 Hz band. It can even be of advantage that the hall helps bring forward these power-demanding very low frequencies. Possible third octave upper tolerance factors of T_{30} relative to the T_{30} at 125 Hz are: T_{30} at 50 Hz :1.8; 63 Hz :1.4; 80 Hz:1.2. If the hall has very low RT at higher frequencies the rise at lower frequencies will be audible more easily and therefore not recommended. A rise at these very low frequencies means that the hall helps that sound to be acoustically amplified; a doubling of RT gives an extra 3-dB sound pressure level. It is important to note that the factor of 1.3 shown in Fig. 5.6 only corresponds to the situation mentioned above where the factor increases with the lower one third octave band. A factor of 1.3, 80 Hz is not appropriate. The higher value of acceptable RT in the 63 Hz octave band compared to the 125 Hz band is believed to have something to do with the human ear's relative insensitivity to sound at these low frequencies (Fig. 1.13).

Recommended Reverberation Time for a Given Hall Volume

A safe choice when designing a venue is to choose a reverberation time that is constant over a frequency according to the values represented by the solid line in Fig. 5.4. In this figure the combined ratings of sound engineers and musicians are the basis of the size of the circles for each venue; larger dots mean a better combined rating. The line is a best fit within the largest circles; the five best halls were given double weight compared to the halls rated numbers 6–10. The 10 worst halls were not included in the equation of the line.

This solid line is an average of the frequencies 125 Hz–2 kHz. Often in acoustics such diagrams only include the mid-frequencies, but because, as pointed out above, control of the low frequencies is important in pop and rock music halls these must be incorporated in the recommendation. The dotted line shows the recommended RT with the 63 Hz band incorporated in the average. This was originally done in the *JASA* paper (see footnote 1) but was later left out (see footnote 2) because as mentioned above, the 63 Hz band can be admitted to have higher values of RT.

The acoustics on stage must not differ too much compared to the acoustics of the hall. In small clubs the sound level is a major concern. If the stage area is equipped with a lot of sound-absorbing material then the rest of the hall must be given a similar design. And then RT is apt to drop below the recommendations in Fig. 5.4.

Acceptable Tolerances of T_{30} *in Pop Rock Venues*

In the town of Odense in Denmark, the author was asked to design the acoustics of two different venues. Both were to accommodate pop and rock concerts. Where one, Posten, would exclusively be used for this purpose, the other one, Magasinet, was also planned to host more acoustic acts, such as a solo folk guitarist or stand-up comedy, theatre, and so on. Posten was a completely new building whereas Magasinet was already a music venue and actually rated number 18 out of 20 in the survey. Both venues are approximately the same size. With two similar venues close to each other in a medium-sized town, instead of making identical acoustics, it was suggested to give each hall its own sound. Posten was therefore built with quite tamed acoustics in the entire frequency span (63 Hz–4 kHz).

In Magasinet the only acoustic change made was bringing down the overly long RT in mainly the 125 Hz band (from 2.3 s to 0.9 s) while leaving the hall with a relatively long RT at higher frequencies (1.4 s with some upholstered chairs dispersed around the room). In that hall there is no mid–high frequency absorption material other than that provided by the upholstered chairs (!). The chairs are removable, and when very popular bands are playing the hall holds about 700 standing audience members on two levels. The ceiling height in that hall is about eight meters whereas the balcony and other construction details in the old factory room make it quite diffusive at all frequencies. No large single portion of the back wall is apparent because the audience area is somewhat sloped and partitioned by the balcony. This eliminated the possibilities of an echo effect.

Both halls are very well liked according to musicians and owners. Some sound engineers say that Magasinet, which is not dampened at higher frequencies, has a too-loud stage but most musicians love it because they enjoy a phenomenal acoustic contact with the audience as well as with their own sound, both through strong early and later reflections. The stage room is only dampened at mid–high frequencies by a backdrop woolen curtain. That venue takes a good sound engineer and a professional band, but with that at hand magic can happen. The town is pleased with having such acoustically different but very functional venues.

Completely omitting mid–high frequency damping material in Magasinet was not planned. It was the idea to install a woolen curtain to be drawn in the opening of the balcony that would make up for the presence of an audience there when the balcony was not in use. That was never installed due to lack of financing after the complete restoration of the venue in 2007. Furthermore, it had been planned to install just a little porous absorption in the perimeter of the ceiling in both the audience and stage areas but this has largely proven to be unnecessary in as much as the hall owners are overly happy about the result due to the positive feedback they get from most musicians and audiences. The RT was brought down primarily in the 125 Hz band but also somewhat in the 63- and 250 Hz bands by installing tuned membrane absorbers in the entire ceiling, also in the stage area, as well as on the large rear wall behind the backdrop on stage. The before and after curves can be seen in Fig. 5.5. The change of RT at higher frequencies (light grey ellipse) is due to a higher number of upholstered chairs during the "after" measurement.

The author is convinced, that envelopment and "togetherness" in general shall be obtained from a higher value of RT at higher frequencies, not necessarily just to create a frequency-independent reverberation when the hall includes the audience. There can possibly even be a rise with the audience in place. This is also where a unique sound for venues can be obtained without jeopardizing the overall acoustic impression. Magic will happen in such halls. Also there will be songs that work less well, but never to a degree of the unacceptable. It's like red wine: a $12 Australian Shiraz will do the job. That resembles a flat frequency response according to Fig. 5.4. But with a $50 red wine, chances are you will get an unforgettable experience, although it may not be appreciated to its full potential with certain dishes.

Derived from that experience it seemed appropriate to suggest a set of acceptable tolerances around the recommended T_{30} shown in Fig. 5.4 also at higher frequencies in halls above some 1,000–2,000 m^3. These tolerances are shown in

Fig. 5.6. The recommended T_{30} values in Fig. 5.4 correspond to a factor of 1 in Fig. 5.6. This yields the following recommendations for empty halls of volumes between 1,000 and 7,000 m^3:

1. T_{30} in the 125 Hz octave band should be in accordance with Fig. 5.4. This octave band is extremely dominant; ask any experienced sound engineer. It is by far the band most often encountered as problematic.
2. At higher frequencies, T_{30} can be higher according to Fig. 5.6. This is due to the high degree of absorption provided by the audience and the air, and due to higher directivity of loudspeakers at higher frequencies. It is also a fact that at amplified concerts usually artificial reverberation is added to these frequencies by the sound engineer partly to compensate for little natural hall reverberation. These exact T_{30} in each band should be chosen by the acoustical engineer according to what the hall owner is striving for in terms of genre and taste and to what the general architecture of the building suggests. It is a fact, though, that higher frequencies easily get overdampened making the low end stand out more easily. The hall will appear unbalanced.
3. Acceptable tolerances for the factor of T_{30} in the 63 Hz band are as follows: 50 Hz: 1.8; 63 Hz: 1.4; 80 Hz: 1.2 times the recommended value at 125 Hz. A tolerance of a factor of, for instance, 1.4 in the entire 63 Hz octave band is thus not recommended. These tolerances are particularly acceptable if there is a similar increase of RT at higher frequencies that will help balance the 63 Hz band rise. The reasons why a higher value of T_{30} in this octave band is acceptable is partly that the masking effect here is less broad (Fig. 1.13) and that the A-weighted sound level in pop and rock music is usually somewhat lower compared to the 125 Hz band. Also from Fig. 1.9 it is seen that a sound decay in the 63 Hz band becomes less audible to humans sooner than a decay in the 125 Hz band because the higher threshold in quiet at 63 Hz (see Fig. 1.9).
4. Tolerances lower than a factor of 1 from 125 Hz and up are to be used in halls with large balcony areas. It is acceptable here to place absorption material in the ceiling areas underneath the balcony whereby the RT will drop to lower levels.

It must be remembered that the extra reverberation, above the factor of 1, at higher frequencies than Fig. 5.6 allows for, calls for a higher level of early reflections at these frequencies on stage too. If the stage is very big or if there is a very high ceiling above the stage, for instance, a stage tower, it can be recommended to support the musicians' early reflections by a utilizing a set of reflectors that may be mobile and arranged according to the size of the band. Such reflectors can preferably be diffusive. It is also important that the higher T_{30} at mid to high frequencies should not be applied in smaller venues due to the risk of ear fatigue unless the room is very diffusive indeed at these frequencies. On the other hand, if T_{30} is chosen lower than unit 1 because of balconies it is still fine to leave the stage not too acoustically dead.

The fact that higher frequencies can attain higher values of RT can also be seen in the light that the dynamics of music mostly is expressed at these frequencies.

Although examples of this from pop or rock recordings do not exist, it is true for a symphonic orchestra or simply an acoustic guitar: when increasing the level from, for instance, *pp* to *ff* the higher frequencies above some 2 kHz increase much more in level than mid and low frequencies (Pätynen and Lokki 2013). The hall should be able to make these dynamics come forward.

The tolerances given in Fig. 5.6 should be useful for companies manufacturing electronic reverberation systems that emulate real acoustics of halls. Still it must be noted that stage acoustics must be similar to the acoustics in the audience area.

Suitable Reverberation Times in Larger Halls and Arenas

Based on the knowledge that RT in the 125 Hz octave band is the most critical parameter for the acoustic quality of a venue for pop and rock music, as well as on values of RT actually obtained in certain acclaimed venues in Chap. 7 of this book, a graph of suitable RT over a greater span of volume (stretching beyond 7,000 m^3) has been made (Fig. 5.7). This recommendation has no subjective studies associated with it and is only to be regarded as the author's best estimate. It is believed that the cautious acoustic engineer can employ the tolerances in Fig. 5.6 in halls with volumes from approximately 2,000–50,000 m^3, evidently with special attention in large volumes (critical distance) and in very small volumes (need of diffusion). It is also possible that volumes larger than 50,000 m^3 can benefit from higher values of RT at higher frequencies. The RT values given in Fig. 5.7 may seem difficult to obtain especially at 125 Hz. However, compared to values mentioned in a conference paper from 2007 where RT especially,[3] where RT especially for "smaller" volumes of, for instance, 50,000 m^3 are extremely strict, the recommendations in Fig. 5.7 are manageable and shown to be more practically applicable.

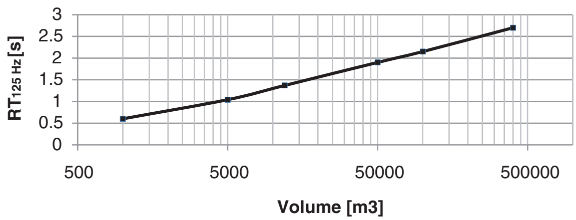


Fig. 5.7 Best estimate of recommendable values of RT in the 125 Hz octave band; a function of volume in empty halls and arenas that present pop and rock music

[3] "Acoustics for large scale indoor pop events;" ISRA, Seville, 2007. Lautenbach and Vercammen.