Possible Acoustic Design Goals in very large Venues hosting Live Music Concerts

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POSSIBLE ACOUSTIC DESIGN GOALS IN VERY LARGE VENUES HOSTING LIVE MUSIC CONCERTS

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1 INTRODUCTION

Every day, somewhere in the world, very big venues are used as auditoria to host some of the most popular musical acts. Most of these venues are mainly used for sports games and fairs. Usually the music arrangements are within the genres of pop & rock and similar modern dance oriented music, but sometimes also other popular styles such as opera or musicals are performed. This paper researches the reverberation properties of 20 European halls in the volume range of 48.000 m^3 to 600.000 m^3 with maximum audience capacities from 4.600 to 21.000 persons standing and seated.

The 20 venues are together with 55 smaller halls described in the author's book on acoustics for pop and rock music [1] and were also briefly dealt with in [2]. In [3] the author has, on the basis of questionnaire responses from musicians and sound engineers, made recommendations for T30 in smaller halls for pop and rock music. These were further refined in [4] where a tolerance field around the recommended T30 versus frequency band was suggested (figure 1).

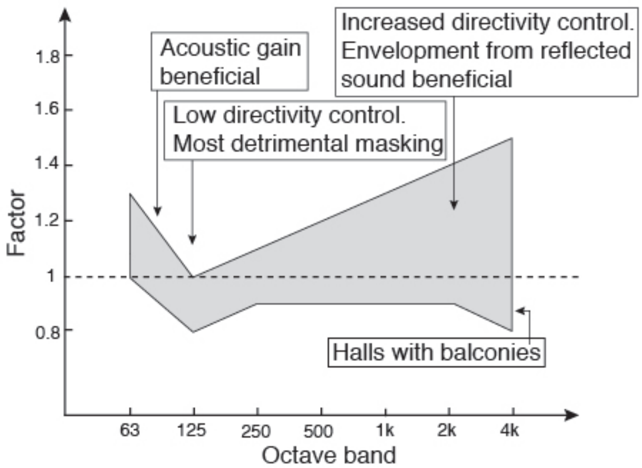

Fig. 1: Acceptable tolerances around T30 in smaller empty pop and rock venues

Due to a 6 times higher absorption coefficient of a standing audience at mid to high frequencies compared to low frequencies and due to the fact that loudspeakers have a higher directivity at mid to high frequencies compared to low, the empty hall without upholstered seats can attain a longer T30 at higher frequencies. Since the bass frequencies are amplified to high levels and since pop and rock music is syncopated and very active at these frequencies the hall must have a controlled bass in order to provide a satisfactory intelligibility of the music. A low T30 at bass frequencies is what with significance distinguishes the best halls from the less well-liked ones.

As a matter of fact, a higher T30 at higher frequencies, at least in the empty hall, seems advantageous since it creates sought-after envelopment, a sense of togetherness for both musicians and audiences while at the same time probably making dynamic expression easier for the musicians [5]. This envelopment shall not be obtained from the bass domain.

Furthermore, this author has witnessed during interviews with hall owners of very dead halls at both low and higher frequencies that professionals still observe problems with the bass in these halls. This leads the author to hypothesize whether an amount of higher frequency reverberation simply *masks* the low frequency challenge to an extend where the bass occurs *defined enough* and where the ear hears a total blend of direct and reflected sound that it actually likes. Our ears may focus positively on the higher frequency reverberation. Such reports have been observed in both small and big venues.

The question is whether such a higher value of T30 at higher frequencies is favorable in very large venues secondary of course to the question of what recommended T30 should be, first of all at bass frequencies.

Further, a debate regarding whether the type of music actually plays a role in such big halls is of course at its place. It seems appealing to propose that if a sense of envelopment at high frequencies is advantageous for pop and rock music then a similar amount of liveliness at bass frequencies in the full venue would also apply to genres that are less active and percussive here. All genres need heavy amplification by means of a sound reinforcement system. The reader should remember, that sound levels at amplified concerts are controlled mainly by the sound engineer who is handling the amplification system, wherefore associations regarding the strength parameter and its T30 dependency are irrelevant.

Since this paper is *not* based on a large number of interviews regarding any genre of music but merely presents examples of what has been possible to obtain in terms of T30 in various European halls, the author prefers to limit the following to only pop and rock music and similar dance music genres with which he is familiar. In [1] the author sets forward a recommended line for T30 vs. volume for larger halls for pop and rock and states that it is simply a best estimate. In this paper the reasoning behind this line will be debated and compared to *another available recommendation* [6]. It is meant as a paper to open for discussions among acousticians on this topic. Since in this way we are breaking new land the author has chosen to mainly focus on the simple but important parameters within reverberation.

2 THE 20 HALLS AND A DEBATE OF THEIR PROPERTIES

The 20 halls measured, are situated in 12 different European countries. All halls were measured with the same equipment described in [1] and otherwise in accordance with standards during the fall of 2010.

2.1 Listing of the halls

The 20 halls are listed in table 1. Their actual names have been left out but can be found in [1]. The halls are simply referred to by numbers. Their number, capacity and volume are listed together with various acoustic properties mainly connected to reverberation.

Name	**Capacity**	**Volume**	**T30125-2k**	**EDT125-2k**	**C80125-2k**	**BR63vs0,5-1k**	**BR125vs0,5-1k**
	Persons	m3	[s]	[s]	dB	-	-
1	13500	110.000	4,15	4,28	-4,06	0,74	0,91
2	11000	150.000	2,46	2,56	-8,98	1,26	1,05
3	16000	600.000	3,71	3,22	0,27	1,89	1,67
4	13000	120.000	2,48	2,07	-0,58	1,46	1,1
5	5500	50000	1,17	1,11	3,15	1,89	0,95
6	15000	230.000	2,81	2,92	1,35	0,98	0,99
7	21000	250.000	2,47	2,22	-0,40	1,46	1,34
8	16000	500.000	2,66	2,49	-2,69	2,58	1,69
9	17000	280.000	2,44	2,03	-0,65	1,7	1,19
10	20000	400.000	2,17	1,83	-2,69	2,06	1,38
11	17960	400.000	4,98	4,4	-4,62	0,76	1,03
12	4600	48000	1,81	1,67	1,65	0,81	1,07
13	6000	50000	2,46	2,33	-2,58	1,62	1,15
14	6500	58000	1,47	1,3	0,95	3,03	1,73
15	15500	270.000	2,43	2,43	-1,10	0,99	1,11
16	9700	150.000	1,61	1,66	0,87	1,64	1,23
17	10000	150.000	3,53	3,36	-2,26	1,33	1,11
18	12000	150.000	2,56	2,41	-3,47	2,1	1,64
19	6238	90000	1,8	1,68	-0,19	0,82	1,07
20	12000	130.000	2,07	1,92	0,53	1,61	1,28

Table 1: Properties of the 20 measured halls

2.2 Reverberation aspects of the halls

In figure 2, T30 as an average over the 63-1k Hz octave bands are plotted against the volume of the halls on a logarithmic scale. The solid straight line was proposed by this author in [1]. The solid thinner curved line was proposed by other authors in [6] and is slightly altered compared to the same authors' first recommendation which is given by the thin, curved dotted line. The curved lines however only applies to big venues according to [6] though it is not stated above which approximate volume it applies.

What immediately strikes is that halls of equal volume attain values of T30 that differs with a factor of more than two. Evidently not all the halls satisfy our expectations of a clear and reasonably defined sound and it is the conviction of the author that it would be easy to obtain evidence that many of the halls are too reverberant.

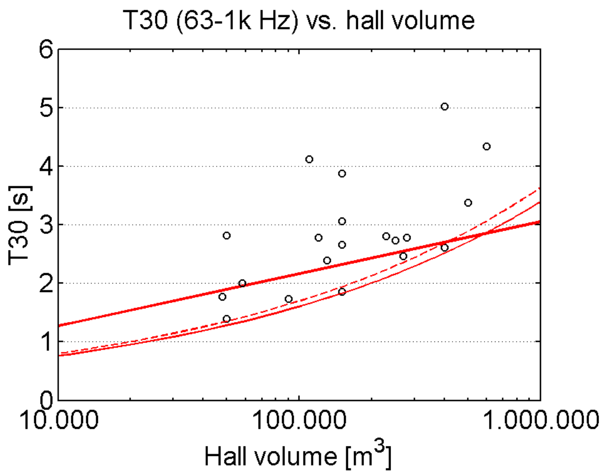

Fig. 2: T30 vs. hall volume for the 20 halls. The straight line is the suggested recommendation by this author. The curved lines were suggested by other authors.

It is noticed that at least three halls attain lower values of T30 than what was proposed by this author. The reasoning behind his line stems from an interview with several people employed by one of the leading and biggest PA system manufacturers in the world. They have on a daily basis contact with the sound engineers of the leading acts that are performing world tours in among others these 20 halls. According to their reports hall number 5 with the lowest T30 and a volume of about 50.000 m^3 *lacks vivacity and envelopment.* It is however a much-appreciated engineering achievement to provide such a low value.

Similarly, in the investigation of smaller halls with questionnaire responses [3] it was stated that one hall with an extremely low value of T30 was deemed too dead by the musicians and was ranked only number 10 out of 20 smaller venues. The musicians simply can't hear or react to the audience. It becomes a somewhat dull, non-social experience, much like playing in a recording studio. It is believed that the audiences lack envelopment too, as stated in the introduction. The T30 versus frequency band of hall number 5 is shown in figure 3. The higher value at 63 Hz is left out of the debate except it should be mentioned that due to the ears' higher threshold to sound at these very low frequencies the sound decay (reverberation) becomes inaudible sooner. This is the reason for the higher tolerance in this frequency band shown in figure 1.

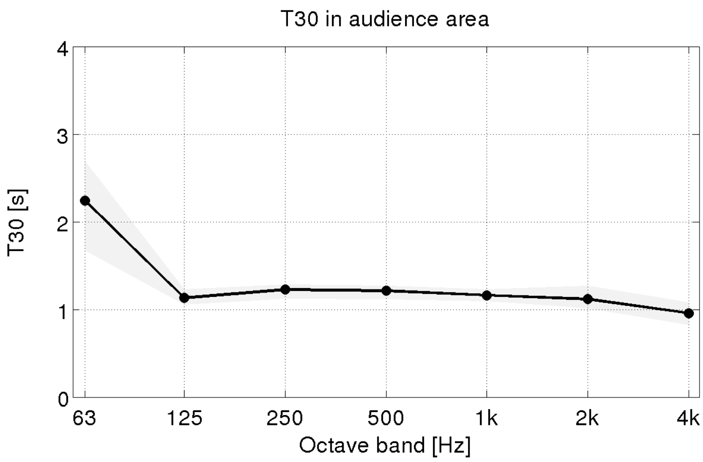

Fig. 3: T30 versus frequency octave band for hall 5

Another hall with a low value of averaged T30 is number 19; the 90.000 m3 hall with a T30 of 1,8 s. This is in fact to a large extent a tent wherefore the 63 Hz T30 is controlled as seen in figure 4. The only absorption in the ceiling is dispersed foam cylinders stretched on wires across. Had the diameter of these cylinders been a little bigger the 250 Hz and maybe 125 Hz octaves would have been more controlled. However, seen in the light that this structure was only meant as a temporary solution back in 1984 when it was built, it might offer quite acceptable acoustics. Still there is a 125 Hz and 250 Hz bump that should be avoided.

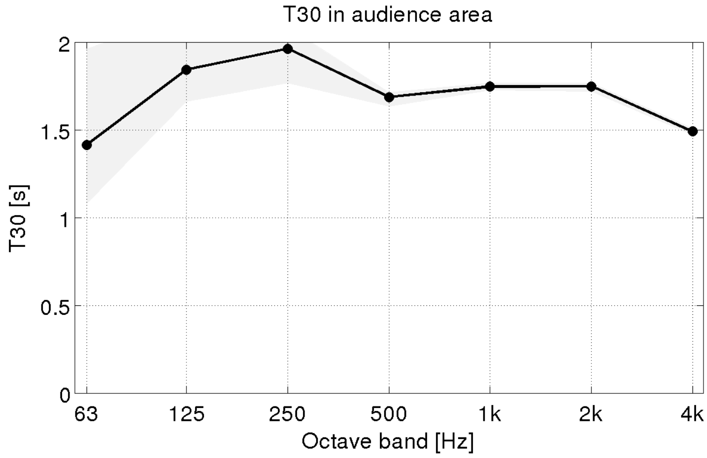

Fig. 4: Hall 19 is to a large extent a tent

Even so its probably better than hall number 14 which is otherwise more or less on the authors recommended line but fails due to a downward sloping T30 vs. frequency as seen in figure 5. Both of these latter mentioned halls have non-upholstered seats.

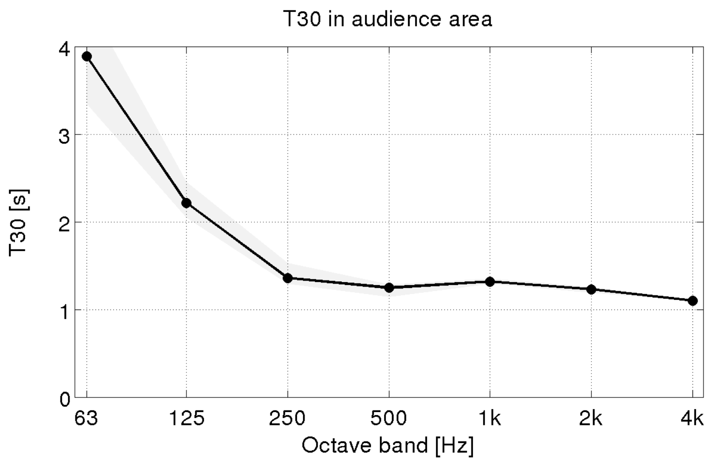

Fig. 5: Hall 14 has an evident problem of a too high LF T30 but has been thoroughly treated with acoustic absorption materials. This is one of a couple of extreme cases and demonstrates the most common design flaw well.

This brings in a debate on Bass Ratios encountered in these venues. In figure 6 the Bass Ratios are calculated as the averaged $T30_{63\text{-}250}$ divided by averaged $T30_{500\text{-}1k}$. It is seen that all halls except a handful have higher values of the harmful LF T30 than MF T30. This is as mentioned the focus point when projecting venues that will host pop and rock music. Some venues have a BR of 1,5 to 2.

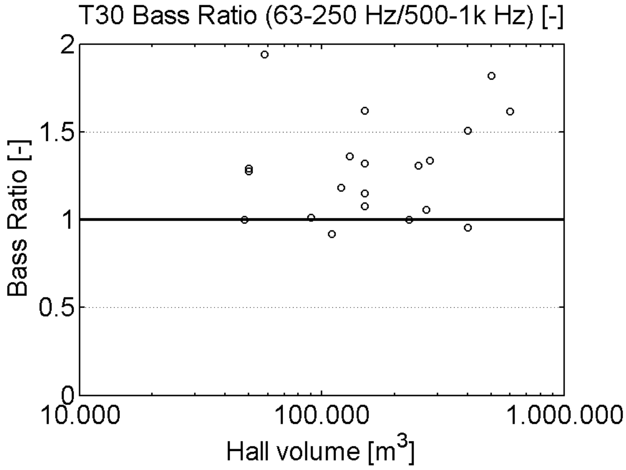

Fig. 6: Only a handful of halls have equal LF T30 compared to MF T30

Due to the higher directivity by speakers and absorption by audience in the 250 Hz octave band and due to the ears relative insensitivity to reverberation in the 63 Hz band, the 125 Hz octave band is by the author deemed as the single most critical band when it comes to pop and rock musical genres. As Early Decay Time is a better descriptor of the part of the reverberation that we hear than T30, which we design the halls after, the ratio of EDT to T30 is a commonly used parameter among acousticians. This ratio calculated only for the 125 Hz band is shown for the 20 halls in figure 7.

This reveals a positive surprise in that the EDT is found to be much lower than T30 in most halls. Maybe a way to make sure that possible envelopment would not blur the total sound impression would be to make sure that these envelopment reflections stem from a part of the hall, which is relatively far away from any listener, for instance the center part of the ceiling. This would probably to a certain degree enable a longer T30 than EDT and thereby a smaller masking effect. Of course then reflections would not be lateral usually believed to have better envelopment properties.

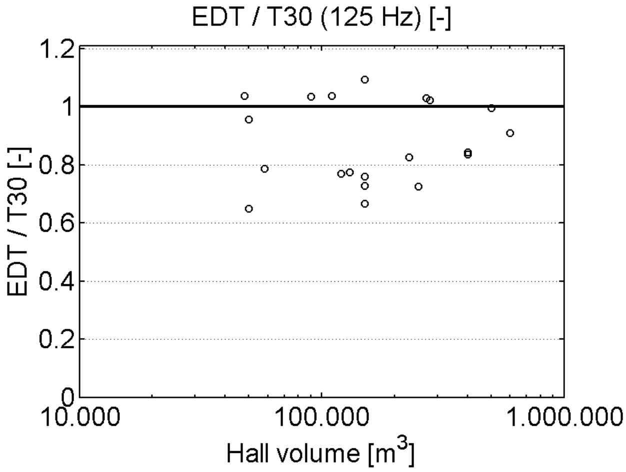

Fig. 7: Most halls have a lower EDT than T30 at the 125 Hz octave band

How about even larger volumes than halls 19 and 14 etc. Can they be too unresponsive too? And in this case, which amount of reflections and which values of T30 would actually be fruitful? The curved dotted line in figure 2 set forth by other authors in [6] is developed from an assumption, that large venue should be 90% reflection free. The equation of that line is T30 [s] = $0{,}038V^{0{,}33}$ where V is the volume of the hall given in m^3. There is no limit mentioned as to at which approximate volume a venue is regarded as large.

The same authors have recently made a recommendation for small venues where the assumption is that the small venue should be 50% reflection free to work well for pop and rock music. Taking into account that their curved line fits well to hall 5, which by some is regarded as lacking envelopment, maybe this assumption is too strict at least for that size venue in the 50.000 m^3 range. Maybe the assumption could be to increase gradually from a 50% reflection free hall (which according to this author works well for a 5.000 m^3 hall) to a 90% absence of reflections for very big halls such as hall 10?

In figure 8 the T30 versus frequency of hall 10 has been plotted. Hall 10 is maybe the world's most well known large venue for pop and rock shows of the greatest stars. It is situated in London. One of pop music's biggest geniuses, Michael Jackson, was supposed to have played 50 shows here during 50 consecutive days but tragically passed away before. It's an acclaimed hall also acoustically and when looking at this size hall in detail it is obvious that it's difficult to gain greater control over the 125 Hz band and especially the 63 Hz band.

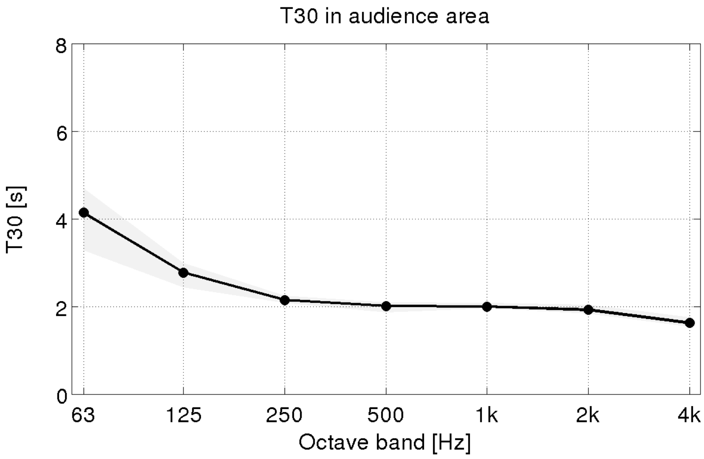

Fig. 8: Hall 10 is the best-tamed venue in the 400.000 m^3 order

This author's recommended line for empty venues is given by equation (1)

T_{30} [s] = 0.56+88e-6*V, (1)

where V is the volume given in m^3.

- The line *verifiably* works down to smaller sized empty venues in the range 1000 m^3, which is the volume at which the T30 = 0,56 s should be used, to about 10.000 m^3.
- It is the conviction of this author that a T30 in the 125Hz octave band anywhere between the curved lines and this author's straight line in figure 2 is appropriate although no investigations among professionals prove this.
- T30 at mid frequencies must be according to the author's recommendation although no investigation among professionals proves this.
- Possible tolerances around these recommendations should be used with caution and focus on obtaining a flat T30 response versus frequency for the *occupied* space. This may not be advantageous in big venues above some 100.000 - 200.000 m^3. No investigation among professionals proves this.
- For volumes above app. 400.000 m^3 this author's recommendation may not be realizable wherefore the dotted curved line in figure 2 should be applied.

2.3 C80 clarity aspects of the halls

In figure 9, C80 is plotted against T30. Hall 5 has the overall best clarity, which is to be expected. It would be of interest to carry out investigations that may lead to explanations to the low value of C80 in for instance hall 2.

The correlation coefficient is -0,51. The author has previously found a -0,73 correlation coefficient between D50 and T30 for 20 smaller Danish halls that present pop and rock music.

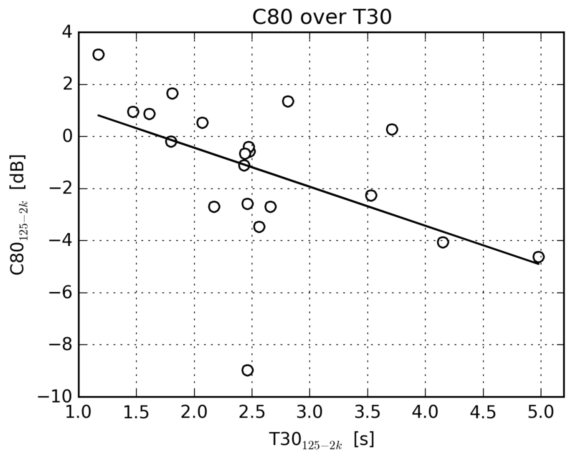

Fig. 9: C80 versus T30. There is a correlation of -0,51

In figure 10, C80 is plotted against hall volume on a linear axis. This shows a very vague correlation coefficient of -0,17. There is no real indication that for instance bigger halls have a lower C80 among these 20 venues.

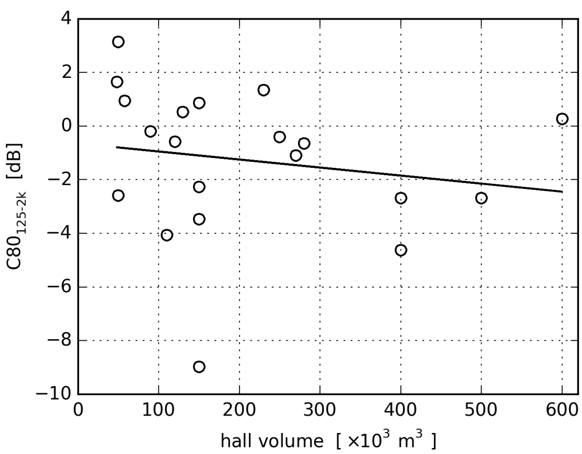

Fig. 10: C80 plotted against hall volume on a linear axis for the 20 halls.

2.4 Practical solution for lowering T30 at LF and MF at single events

As a practical solution, the author would like to show case a new method for decreasing T30 in smaller or large venues also at low frequencies for single events. At the Eurovision Song Contest 2014, the worlds' second biggest yearly television event, a Danish abandoned former shipyard with an up to 13 s LF T30 was chosen as venue. A new invention of inflated membrane absorbers by the author was used and a T30 of 4 s without audience was achieved (figure 11). The volume of the venue was 700.000 m^3 and 7000 m^2 of the absorption product was used. The technology has been used in several other projects since then and is also available in a permanently installed on/off version for multipurpose halls that need to vary the acoustics according to type of music. This is being implemented in halls around the world.

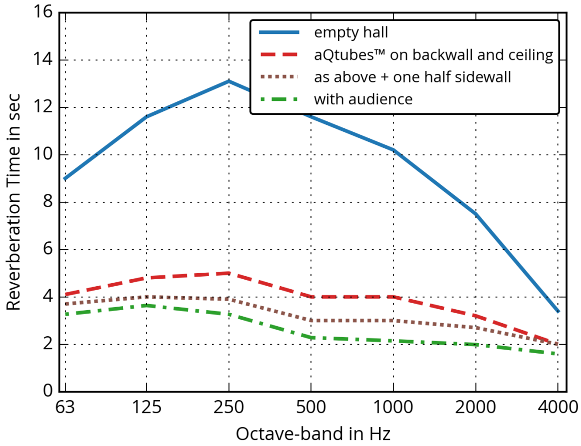

Fig. 11: Measurements of T30 in ESC 2014 venue, before and after installation of the inflated membrane absorber product.

3 CONCLUSION

A thorough questionnaire investigation among musicians and sound engineers performing in large venues is lacking. The recommendations in this paper are to be regarded as hypotheses. An assumption by other authors leads to their recommendation, which may be applicable at least for the 125 Hz octave band and maybe for the entire frequency spectrum 63 Hz – 1 kHz for very large venues.

Due to the risk of lack of envelopment and vivacity it is the author's opinion, although not backed up by evidence, that T30 at mid frequencies should not be lower than his recommended line set forth in this paper which is the author's best estimate for appropriate T30 in larger venues for pop and rock music. An actual investigation as to appropriate C80 values would be of benefit as well.

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