On a new, variable broadband absorption product and acceptable tolerances of T30 in halls for amplified music

by N Adelman-Larsen, E Thompson and JJ Dammerud

ABSTRACT

Previous studies have shown that what distinguishes the best from the less well liked halls for pop and rock music is a short reverberation time in the 63, 125 and 250 Hz octave bands. Since a quite long reverberation time in these frequency bands is needed in order to obtain warmth and enough strength at classical music concerts, variable acoustics must address these frequencies in order to obtain desirable acoustics in multipurpose halls. Based on the results of a previous study of Danish rock venues as well as three newly built halls, acceptable tolerances of T30 were investigated. The results suggest that T30 can be 1.4 times as long in the 63 Hz octave band as in the 125 Hz band and attain values of +/- 15% at higher frequencies compared to previously determined values. A variable broadband absorption product is also presented. Absorption coefficients are approx. 0.8 in the 125, 250, 500 Hz bands, 0.6 at 1 kHz and decreasing at higher frequencies and in the 63 Hz band when in the ON position. In the OFF position the product attains absorption values between 0.0 and 0.2.

On a new, variable broadband absorption product and acceptable tolerances of T_{30} in halls for amplified music

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Abstract

Previous studies have shown that what distinguishes the best from the less well liked halls for pop and rock music is a short reverberation time in the 63, 125 and 250 Hz octave bands. Since a quite long reverberation time in these frequency bands is needed in order to obtain warmth and enough strength at classical music concerts, variable acoustics must address these frequencies in order to obtain desirable acoustics in multipurpose halls. Based on the results of a previous study of Danish rock venues as well as three newly built halls, acceptable tolerances of T_{30} were investigated. The results suggest that T_{30} can be 1.4 times as long in the 63 Hz octave band as in the 125 Hz band and attain values of +/- 15% at higher frequencies compared to previously determined values. A variable broadband absorption product is also presented. Absorption coefficients are approx. 0.8 in the 125, 250, 500 Hz bands, 0.6 at 1 kHz and decreasing at higher frequencies and in the 63 Hz band when in the ON position. In the OFF position the product attains absorption values between 0.0 and 0.2.

Introduction

Please note that the abstract has been changed from that in the program: Tolerance of T_{30} in the 63 Hz octave band can be a factor of only app. 1.4 higher than the value suggested in fig.3.

Today's musical geniuses are equally likely to be performing within the pop, rock, or jazz music genres as they are to be performing classical music. From the point of view of the musicians, live concerts are becoming increasingly important because of declining sales of recorded music. Both for the sake of musicians as well as to serve the vast masses of audiences attending their concerts, more focus on suitable acoustics for pop & rock appears relevant. Part one of this paper will look into what deviations from recommended T_{30} can be tolerated and used advantageously. Many classical, pop and rock concerts are held in multipurpose venues in performing arts centres, recital halls, etc. In order to try to adapt the acoustics of these halls to the different needs of these different genres, variable acoustic systems – passive as well as active – are often employed in such halls. A new solution to this challenge, a broadband acoustic absorber that can be switched on or off as needed and is installed in the ceiling area of such halls, is presented in part two of the paper.

Of course, for most room-acoustic matters, many parameters other than simply T_{30} are of interest. For instance the level of the reverberant sound field compared to the level of direct sound is often decisive for subjective impressions of the acoustics of a room. Since this ratio is correlated with T_{30}, and T_{30} is the primary criterion used in selecting materials in an acoustic design for a given hall volume, T_{30} as a function of hall volume is the primary focus in this paper. The direct-to-reverberant energy ratio decreases with distance from the sound source, which is why the shape of a room is critical in early phases of the design process. Further, in [1] it was found that sound engineers preferred a very short T_{30}, but musicians preferred a slightly longer reverberation time. The reason for this is probably that the musicians prefer a sensation of envelopment and "togetherness" with each other and the audience. It is believed, but not proven, that the audience also has this desire. This also implies that people are not attending live concerts to

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experience a high fidelity sound quality adventure, but rather a social experience. To achieve this, a certain level of reverberant sound at live pop and rock concerts is required, so a design goal for a hall could be to create lateral reflections creating a sensation of envelopment.

Part one: Acceptable tolerances of T_{30} in halls for amplified music

Background

In [1], suitable reverberation times as a function of volume for mid-sized pop & rock venues up to approximately 7,000 m^3 were determined. It was also found that what distinguishes the best from the less appropriate halls is a significantly lower value of T_{30} in the 63, 125 and 250 Hz octave bands. This is shown in Fig. 1, where the average T_{30} divided with their volume of the ten best and the ten least well liked halls, according to a subjective study among both musicians and sound engineers, are plotted against frequency bands. The reason for this is probably the high sound level in those bands, in conjunction with the low degree of absorption that the audience provides at low frequencies, as well as the loudspeaker output in this range being close to omnidirectional. The reverberant bass sound masks even the direct sound of, for instance, the vocals. Furthermore, the bass levels have been reported to increase recently throughout Europe with the introduction of sound level limits at live concerts. A boost in the low frequencies is being used to make up for the lower level at higher frequencies that this limit has introduced.

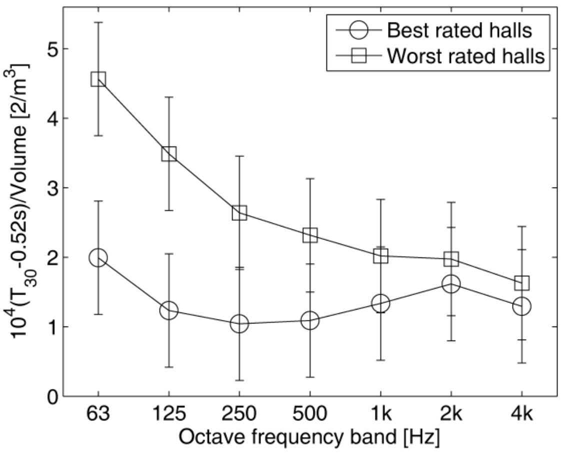

Fig.1: Average T30 divided with hall volume of ten best versus 10 mediocre halls for amplified music

Investigation, results and discussion

In order to further pursue this research and to cross check the results from [1], as three additional mid-sized Danish venues that were built or renovated after [1] was written were investigated. All three venues have been identified overall to have good acoustics among a handful of surveyed musicians, owners and sound engineers (although not all sound engineers agree about the quality of one hall). Objective measures obtained from these three venues may provide a preliminary indication of acceptable tolerances around the recommendable T_{30}. The volumes of the three venues are: 2,300 m^3, 2,700 m^3 and 4,000 m^3 for Fermaten, Magasinet and Skråen respectively. Their T_{30} as a function of frequency is plotted in Fig 2.

Magasinet contains no mid/high frequency absorption at all apart from upholstered chairs, so the reverberation of the hall does not change much when filled by an audience. Fermaten has a balcony level with a surface area of approx. 2/3 of the total ground floor area with ceiling absorption on both levels. The stage was designed with many reflective surfaces directed towards the musicians. Skråen became somewhat over damped at high frequencies because of wall-to-wall carpet and upholstered seats installed by the hall owner after the completion of the hall (without discussing it with an acoustic consultant).

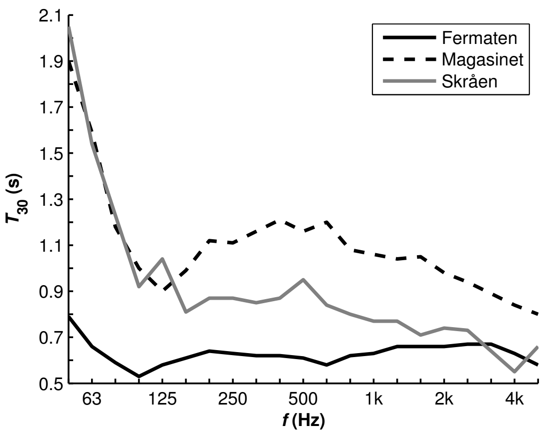

Fig.2: Measured T_{30} for the three Danish venues.

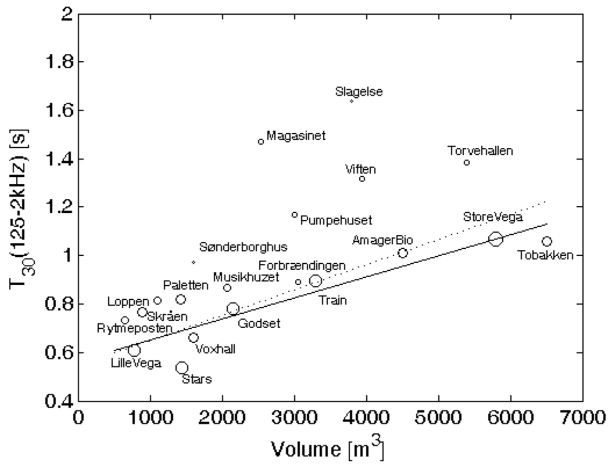

Fig.3: Recommended T30 as a function of hall volume in halls for amplified music. The previous recommendation (from [1]) and the current recommendation are shown with dotted and solid lines, respectively. Larger circles mean better combined ratings by musicians and sound engineers.

New recommendation

At this point, it is necessary to revise our conclusions from [1]. In [1], the graph showing the suitable T_{30} as a function of hall volume was derived as a weighted average of T_{30} in the range 63Hz-2 kHz of the 10 best halls shown in Fig.1. But as seen in Fig.1, which also is from [1], T_{30} in the 63 Hz octave band can be somewhat higher than in the higher octave bands. Not 1.8 times as much as mentioned in [4] – rather 1.4 as derived below. Since these higher values of T_{30} in the 63 Hz octave band bias the average of the T_{30} toward higher values in the higher octave bands, a new recommendation is proposed with a revised graph of T30 vs. volume (Fig. 3). These are the revised values of recommended T_{30} as a function of volume and these will therefore be used in the following discussion.

A separate recommendation for T_{30} in the 63 Hz band is then necessary. This is suggested in the next section as an acceptable tolerance for that octave band.

T30 in the 63 Hz octave band. In [1] the average of $T_{30,63\text{Hz}}$ in the 10 highest ranked halls is a factor of 1.24 higher than $T_{30,125\text{-}2\text{kHz}}$. In the highest ranked hall the factor is 1.56 (while $T_{30,125}$ is only a factor of 0.96 times $T_{30,250\text{-}2\text{kHz}}$) . In fact this factor is only 1.43 for the mediocre halls. The reason why this value is not higher is at least twofold: the halls with bass problems also have a high T_{30} at 125 Hz affecting the ratio (for instance Viften, Slagelse, Magasinet have in average a ratio of $T_{30,\,63\text{-}125\text{Hz}}\,/\,T_{30,250\text{-}2\text{kHz}}$ of 1.62); secondly, at least in Torvehallerne, a too high T_{30} *only* at higher frequencies and a lack of means to deliberately support such acoustics (as discussed below) causes the bad rating.

Out of the 3 new halls, Skråen was the only hall that was judged boomy by a band. It is believed that the boominess is not due to the rising curve below 100 Hz per se (see Fig. 2), but rather because of the high ratio of bass reverberation times including the peak at 125 Hz to mid/high frequency reverberation times. Magasinet supports similar bass reverberation times with better perceived sound quality because of a better balance of low to high frequency reverberation times.

It therefore appears appropriate to incorporate a separate tolerance for the 63 Hz octave band that can be up to 1.4 times the recommendation in Fig. 3, equal to the suitable T_{30} within 125–2000 Hz for a specific volume,. This factor may only be acceptable if the T_{30} curve rises steeply towards the 50 Hz third octave band. Possible third octave tolerances are: T_{30} at 50 Hz :1,8; 63 Hz :1,4; 80 Hz:1,2. Here expressed as a factor of the recommended value found in fig 3. In some situations, the available absorption leading to an acceptable reverberation time in the 125 Hz octave band will also lead to a reverberation time in the 63 Hz octave band of reasonable values.

On the other hand, a reduction of T_{30} from 125 to 63 Hz is not something to strive for since it will take more power to provide an adequate sound level which furthermore would decrease significantly with distance from the source. A factor within 1 to 1.4 for T_{30} at the 63 Hz compared to the 125 Hz octave band therefore appears to be an optimum range.

T30 in the 125 Hz octave band. Since we know that the reverberation times in the 63 Hz and 125 Hz bands are factors that distinguish the quality of rock halls (Fig.1) and that the T_{30} in the 63 Hz band can be longer than at higher frequencies, T_{30} from 100 to 200 Hz seems to be an important range to keep to the level suggested in Fig. 3. In [1] average of $T_{30,125\text{Hz}}$ in the 10 highest ranked halls is a factor of only1,02 compared to $T_{30,250\text{-}2\text{kHz}}$ and just 0.96 in the highest ranked hall. An enormous amount of amplification is used in this range while at the same time the hearing of human beings even at loud levels rolls off below 100 Hz , which may be one reason why acceptable $T_{30,125\text{Hz}}$ is lower than acceptable $T_{30,63\text{Hz}}$. Further, there is an indication in [1] that a standing audience absorbs more sound power in the 63 Hz octave band than in the 125 Hz octave band.

Tolerances of T30 at higher frequencies: T_{30} normalized with respect to volume of the 10 best halls from [1] have been plotted in Fig.4. The variations in the mid frequency range seem to lie within an interval of +/- 0,10 - 0,15 s corresponding to +/- 15 %. The lower limit is the hall Stars which is rated as number 10 and too dry by musicians. But as described below such a low T_{30} is acceptable if a large area of the venue is covered by balconies unlike the venue Stars. This makes the volume of the venue appear smaller than what it actually is.

As mentioned above, the acoustics in general of the 3 venues are judged to be fine according to most musicians and sound engineers. With regard to further subjective judgments of these three venues, the musicians in one of the loudest Danish bands found it pleasant that in Magasinet they were able to hear the audience so well. Some sound engineers of amplified performances judge the stage at Magasinet as too live. A well-known Danish performer, unlike other bands, commented after playing with an amplified acoustic guitar duo in Skråen that the acoustics were 'too dead'. Another famous band commented that the stage was boomy.

In order to understand possible reasons for these comments, the objective data are studied: The results for T_{30} within 1/3 octave bands for the three Danish halls are shown in Fig. 1. Suitable values of T_{30} for the three volumes are, according to Fig. 3, 0.8 s for the two smallest volumes and 0,9 s for the bigger volume, with T_{30} averaged over the 125 Hz – 2kHz octave bands as suggested in Fig. 3. The actual measured T_{30} for the three halls when usng this average is 0.62, 1.12 and 0.99 s for Fermaten, Magasinet and Skråen respectively. The corresponding deviations from the recommended values are –23, +40 and +10 %.

At amplified music concerts in especially dead rooms, the sound engineer adds artificial reverb on higher pitched instruments or on the higher frequencies of instruments that have a broad range. He would never add reverberation to bass or bass drum other than for a special effect. As mentioned, reverberation at low frequencies, regardless of whether it comes from the hall itself or is added artificially, adversely affects pop and rock concerts. Also from this perspective, it seems plausible that as long the hall is dry at low frequencies it can be more live at higher frequencies.

After our previous study [1] was published, some sound engineers have reported that they like the hall to add reverberation at higher frequencies since the combination of artificial and real reverberation sounds more natural than artificial reverberation alone, and also because they want themselves and the audience to feel enveloped in sound. It seems that musicians and a group of sound engineers prefer some reverberation at higher frequencies and the values in Fig. 3 as well as in this section suggest that a part of the hall should be left without mid/high frequency absorption in order to achieve a sensation of envelopment. Usually envelopment is related to lateral reflections, which suggests that sound absorbers should be placed in the ceiling. Another group of sound engineers likes the halls to be as dead as possible. In fact, the hall Stars in Fig. 3 was the preferred hall by the group of sound engineers rating the 20 halls in [1]. Other sound engineers that the author has interviewed at later occasions have expressed that they dislike almost anechoic rooms.
If relatively live acoustics are designed at higher frequencies, care must be taken in the design of the shape of the venue as well so that the musicians receive enough early support and so that the stage matches the liveliness of the hall. Special caution must also be shown on the design and installation of the PA speaker system in such a room. If the back wall is not absorbent, and, with some speakers in the array pointing toward the rear wall an unwanted for extra reverberation and maybe even echoes will be created. The lack of early support and an overdone speaker installation with minimal back wall absorption is believed to be the reason for a poor rating by musicians and engineers at Torvehallerne.

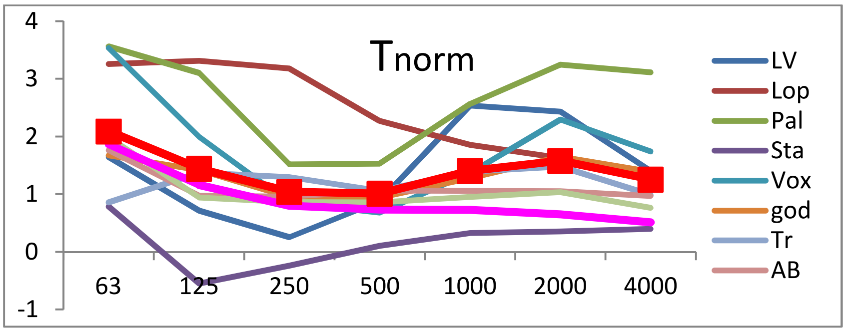

Figure 4: Measured T_{30} for ten best halls [1] normalized with regards to their volume

Hypothesis referring to fig 5:
1) T_{30} in the 125 Hz octave band should be in accordance with the new values in Fig. 3.
2) at higher frequencies, T_{30} can be up to 30 % higher, or more, than this depending on what the hall owner is striving for genre and taste wise.
3) at frequencies above 1 kHz, T_{30} can maybe be even higher due to the high degree of absorption provided by the audience AND to the 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. Of course the air will in reality lead to lower T_{30} above 2-3 kHz.
4) T_{30} at 50 Hz: 1.8; 63 Hz: 1.4; 80 Hz: 1.2 times a factor of the recommended value at 125 Hz.

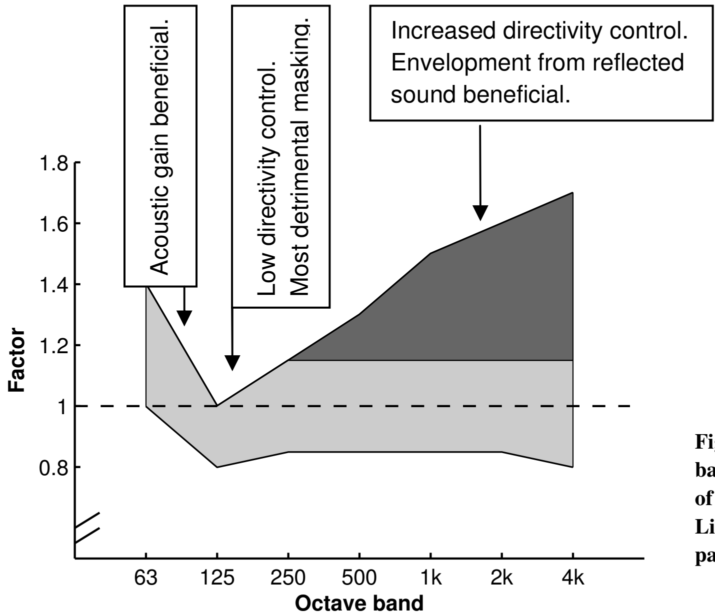

Fig. 5: Approximate factors of T_{30} in the octave bands 63 Hz to 4 kHz relative to average value of T_{30} within 125 to 2 kHz as proposed in fig.3. Light grey area: tolerances as debated in this paper. Dark grey area: possible tolerances.

Stage: Some results from the questionnaires leading to [1] was not included in [1]. The authors would like to share a common comment at this point: Acoustics on stage should not be deader than in the hall and should preferably mainly be absorptive in the ceiling. An effect of early support as pointed out by Gade [3] that is enjoyed by classical musicians is believed to also be beneficial at pop and rock concerts to certain extent since it is lowering the musicians' reliance on monitor speakers including in-ear monitoring. Moreover, the musicians want to be in the same acoustic climate as the audience and want to feel enveloped in sound – also the sound from the audience. But they don't want to be enveloped in the sound of the PA system. Of course there is always the possibility that the sound engineer wants to avoid too much "leakage" of direct stage sound into the hall where he/she and the audience could benefit from the refined sound of the PA system. This can lead to the famous "evil spiral" arising between the level of the PA system and the level of the monitor system and band each unit forcing the other to increase level by turning up themselves. And evidently when the sound of the band is not pleasant an absorptive stage environment is preferred. The reverberation times in fig. 3 will lead to a quite dampened stage if the above mentioned rule of somewhat equal acoustics on stage and in the hall is followed.

Part Two: New on/off broadband absorption product

From our knowledge that a low T_{30} at low frequencies is required for amplified music while warmth and enough strength demands a higher value of T_{30} at classical music concerts, attaining a high absorption coefficient over a broad spectrum at lower frequencies has been one aim in the development of this new variable absorber. The basic technology of soft inflatable membranes as means for variability of reverberation time in multipurpose venues was presented in [2]. This new product, the AqTube™ absorber, enables an inexpensive way to achieve enough absorption variability when installed in the ceiling to make it possible, for example, to present both symphonic music and rock concerts in the same venue with favourable acoustics. The product can be installed permanently for ON/OFF use as seen in Fig 6, or, since it is extremely thin and light, it could be installed temporarily in any hall. Table 1 shows measured absorption coefficients, α, in the on- and off-positions, respectively.

The absorption coefficients were measured in the reverberation chamber at the Technical University of Denmark. Four absorbers each with a length of 10.8 ft were placed side by side as baffles. Hence the alpha values obtained correspond with the projected surface area and thereby the ceiling area. The arrangement that was measured for this purpose needs a cavity above e.g. a suspended, acoustically transparent ceiling of approx. 4.3 ft.

If single tubes are mounted side by side in the ceiling in a building of e.g. 6,000 m^3 or L·W·H = 90·60·30 ft with a T_{30} of 2 s then the 5.400 ft^2 of the product will lead to a T_{30} at 125 Hz of 1.0 s when active with an absorption coefficient of 0.8 or 1.1 s with an alpha of 0.6 referring to Table 1. These values are believed to be optimum values for choir respectively pop/rock for this size venue. Further, values in between the extremes can easily be achieved by activating any number of tubes. The reason that the product absorbs more in the 500 Hz band than for instance in the 125 Hz band is a combination of fire regulations and physics. The roll-off of alpha in the 63 Hz band and above 1 kHz was a part of the design strategy. Should these frequencies be incorporated the cavity of the absorber would have to be larger. There does not seem to be a need neither for higher values of α at these frequencies nor is a larger cavity practical. Moreover, the high frequencies are diffused by the convex shape of the activated cylindrical product leading to a somewhat higher absorption in reality than what is found in the reverberation chamber due to the presence of the abundance of absorption at high frequencies provided by the audience, etc.

Table 1: Measured absorption coefficients for AqTube™ in the "ON" and "OFF" positions respectively.

f [Hz]	63	125	250	500	1k	2k	4k		f [Hz]	63	125	250	500	1k	2k	4k
α ON[1]	0.4[2]	0.8	0.8	0.9	0.6	0.3	0.3		α OFF	0.0	0.0	0.1	0.1	0.2	0.2	0.2
α ON	0.3[2]	0.6	0.6	0.7	0.4	0.2	0.2		α OFF	0.0	0.0	0.1	0.1	0.2	0.2	0.2

1) May be able to achieve only in certain states depending on fire regulations. 2) Uncertain measurement

If the PA system is designed correctly, avoiding loudspeakers aimed directly against the back wall, suitable conditions for pop and rock concerts and rehearsals are obtained. Otherwise, variable porous absorbers can be employed on the rear wall leaving the low frequencies to be absorbed by the AqTubes. A lowered acoustically transparent ceiling can be mounted underneath the absorbers for aesthetic or utility purposes. This may include attachment of lighting, ventilation, fire sprinklers etc. It takes approx. 4 min. to activate the system. The air pressure of the system is constantly surveyed to ensure maximum absorption at all times. The material is flame retardant to the European B,s1,d0 and US NFPA 701 and ASTM E 84 standards. The system has not yet undergone a complete acoustic or fire certification in the U.S.A. It is the hope that the product will be used to benefit amplified as well as classical music in many applications from music schools, recital halls, arts performance centres, multi-purpose halls etc. The technology is patented [5].

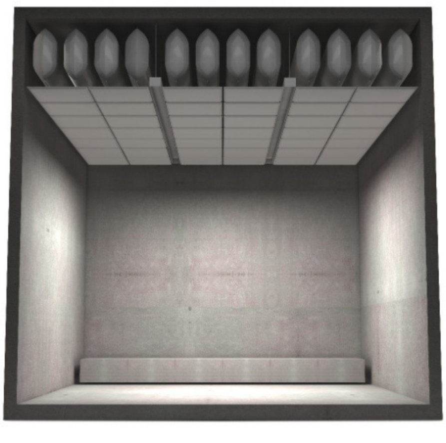

Figure 6: A lowered sound transparent ceiling is mounted beneath the AqTubes™.

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