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ACOUSTICS FOR LARGE SCALE INDOOR POP EVENTS

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INTRODUCTION

For over decades, pop concerts were held wherever possible, from farmer sheds and squatted dwellings to theatres and football stadiums. But as time goes by, pop music has become big business, it has become more professional so to say and the nuisances accompanied due to the less suitable buildings are not accepted anymore. Besides that, the regulations for sound emission to dwellings have become more strict. This led to the demand for buildings especially designed for pop concerts. And that's exactly what happened in the Netherlands: in the last ten years there's been quite an explosion of new or thoroughly renovated pop stages, most of them with a capacity between 500 and 2,500 visitors.[1]


Figure 1. Heineken Music Hall with audience

The real pop stars, who attract much more public, were still confined to football stadiums or multipurpose halls in order to give their concerts. Because these spaces were never designed for pop concerts, the acoustics had to be taken for granted. Unless the stadium has an open roof, these halls usually have a too long reverberation time, especially in the low frequencies. In France, the Ministry of Culture decided in the mid 1970's that it was time to develop specialised facilities for pop music. In 1984 the first Zenith was built in Paris and was followed by six more in the years after. The realisation of the Heineken Music Hall in 2001 was in the Netherlands the first step in providing a hall for pop concerts with a capacity of over 5,000 visitors combined with acoustics especially designed for pop music. This was followed by the plans to adjust the existing football stadium the Amsterdam ArenA in order to make the acoustics more suitable for pop events.

As the halls become larger, the acoustic challenge increases. In this paper we will go into the room acoustical aspects for large indoor pop events, of say more than 5,000 visitors. Acoustical difficulties and some practical solutions are discussed with reference to the Zeniths in France, validation measurements of the Heineken Music Hall, as well as to acoustic modifications in the Amsterdam Arena in favour of pop music. But first we will discuss the preferred acoustical conditions and related critical issues.

PREFERRED ACOUSTICAL CONDITIONS FOR INDOOR POP EVENTS

Pop music usually is reproduced through electroacoustic (PA) systems in order to reach enough loudness at the listeners positions. The sound from the different musical instruments and the singing is mixed at the control table, therefore we don't need reverberation to blend the different musical sounds like in the classical concert hall. In the contrary, for maximum control over the reproduced music, a minimum influence of the hall is wanted. (If reverberation is wanted, it can be managed electronically). So we need to translate this demand to the 'usual' acoustic parameters with which we can predict the outcome during the design process with calculations and with which we can quantitatively review the result after realisation by validation measurements.

A high direct to reverb ratio is the first condition which has to be accomplished for good defenition. The direct sound comes from the loudspeakers and we want a low reverberation level due to the numerous reflections from walls, ceiling and floor. The most used acoustic parameter, the reverberation time, must be short compared to the size of the hall. That statements lacks quantity altogether, but although there will be a measurable decay of sound, due to the dimensions there will be no diffuse sound field, and therefore not a reverberation time in the strict sense of the word. More important than the actual reverberation time, is a flat reverberation spectrum from 63 up to 4000 Hz. Special attention has to be paid to absorbing efficiency at low frequencies: the 63 and 125 octave band. If the reverberation level at low frequencies is high, a soup of sound 'swallows' all higher frequencies and kills the definition.

To accommodate 5000 visitors or far more, the dimensions of the hall become so large, that the time delay of first order reflections must be taken into account. A strong enough reflection which arrives at the ear of the listener 50 ms after the direct sound, can be heard as an echo [2]. 50.10^{-3} s * 343 m/s tells us that at normal room temperature, the extra distance travelled by the sound is 17m, which is clearly possible for a ceiling, side and/or rear wall reflections. A stage depth more than 8.5 m is not uncommon, so with loudspeaker clusters on the edge of the stage or just in front of it, even the stage wall could be a problem. According to listeners tests carried out by Haas [3], the later the arrival of the delayed sound (or reflection), the more disturbance it brings to the listeners. The larger the room, the longer it takes for the relative high energetic, first-order reflections to arrive at the listeners ear. As can be seen from figure 2, the delayed signal must be about –10 dB relative to the direct sound to neglect the percentage of disturbed listeners.

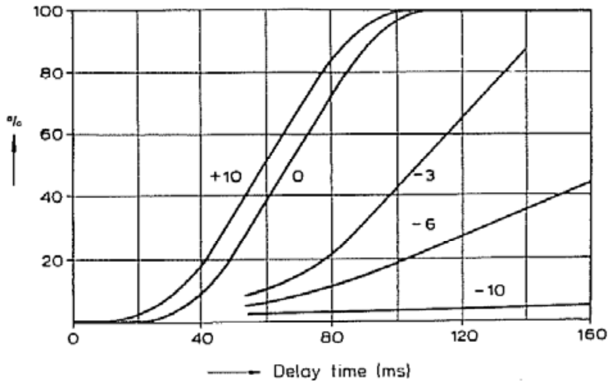


Figure 2. Percentage of listeners disturbed by a delayed speech signal

$$L_p = 10\log\frac{p_{eff}^2}{p_0^2}\ \text{dB},\quad I = \frac{p_{eff}^2}{\rho_0 c}\ \text{W/m}^2\quad \text{for a plane travelling wave}$$

$$\Delta L_p = 10 = 10\left(\log\frac{p_{i,eff}^2}{p_0^2} - \log\frac{p_{r,eff}^2}{p_0^2}\right) = 10\log\frac{p_{i,eff}^2}{p_{r,eff}^2} \Rightarrow p_{r,eff}^2 = 0.1 p_{i,eff}^2$$

So in order to reduce the level of a reflection with 10 dB, the reflected intensity must be only 10 % of the incoming intensity, and the (average) absorption should be no less than 90%.

The use of loudspeaker systems with high directivity, such as arrays, aimed at the public can't create the acoustical conditions wanted. At low frequencies the directivity gets less, the lower the frequency, the more the loudspeaker system becomes omni-directional and acoustic energy is sent where it's not wanted. It then nevertheless creates a high low frequency reverberation level. Also the presence of side-lobes with strong coloration of sound can cause inconvenient side-wall reflections.
Another problem that is not solved using high-directivity systems in rooms with too much reverberation, is the 'soupy' sound at low frequencies. Audiences do absorb quite a lot sound energy, but not in the low frequencies. The sound absorption of audiences is about 20 % at 125 Hz, and 10% at best at 63 Hz. Besides, most pop groups bring their own PA system and don't want to use the permanent system suspended in the hall. Their own system is mostly not a high-directivity system, but is chosen for excellent sound quality.

The most important requirement for large rooms for pop events is therefore a radical suppression of first order reflections. This can be accomplished with broad band absorbing materials on ceiling and all walls with an average absorbing coefficient of 0.9 in the frequency bands 63 – 4000 Hz.

The above mentioned can be extrapolated to some volumes with a reference ratio of height to width to length of 1:2:4. For these reference volumes the "preferred" average reverberation time for the unoccupied situation can be calculated using the reverberation formulae $T_{60} = 0.161\frac{V}{A+4mV}$.

The calculated data is presented in the figure 3.

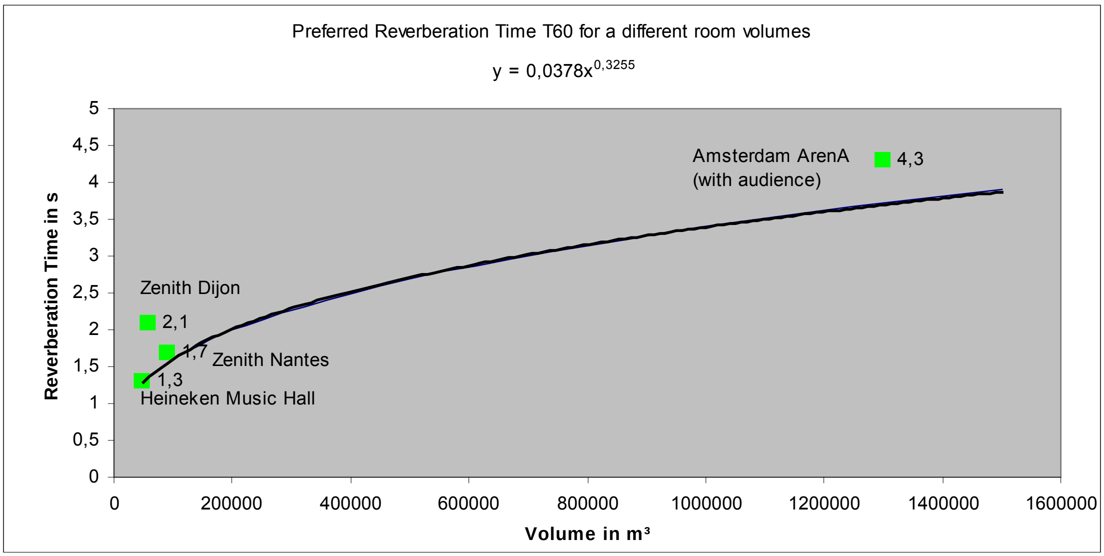


Figure 3. Calculated Preferred Reverberation Time for different room volumes and the RT's of the discussed halls

The matched approximation formula is $T_{60} = 0.038V^{0.325}$ In which V is of course the volume.
This can be used as rough guidance for a room acoustic requirement in the early stage of the design for a large indoor pop accommodation.

To secure a low reverberation level, the ratio of direct to late sound should be at least +5 to 6 dB, measured with an omni-directional source. With the use of a good PA system, this in practice will result in a direct to late ratio of 10 dB or more.

If the hall is also used for multi-purpose events, additional requirements on speech intelligibility should be made. For good speech intelligibility the AL_{cons} [4] should be less than 10% at every listeners position, if less critical, a sufficient speech intelligibility is achieved at an AL_{cons} of 15 % maximum.

In really large halls more loudspeakers than the stage clusters are used to create enough loudness or definition under balconies or at great distance from the stage clusters. These 'extra' loudspeakers should be on perfect time delay, and not too loud. They can only be used to add some sound where wanted, if too loud, the emitting sound will be causing a 'fake' reverberation (level) and can be perceived as an echo at other locations then the addressed.

THE ZENITHS

Since the 1970's the requirements on the room acoustics of the Zeniths developed. The first hall adjacent to the Paris "boulevard periferique" was developed as a provisional pop facility. It was build like a tent of a very heavy tissue, situated close to the Cité de la Musique. Later on, this design is further developed for six other similar halls all over France. The acoustical requirements were updated on basis of the experience. More and more the walls and the ceiling are covered with sound absorption. These halls can accommodate an audience of up to 7,200 people (standing).
The most recent build Zeniths are the ones in Dijon and Nantes. In figure 3 the reverberation time of both is indicated. In Dijon the reverberation (2.1s, 63-4000 Hz) is estimated as too long for the sound check in the hall without audience. The more dry acoustics (1.7s, 63-4000 Hz) in Nantes is estimated as adequate. The relative long reverberation times at low frequencies seem to become more critical in recent years.

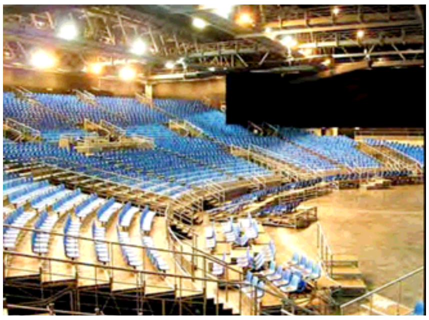
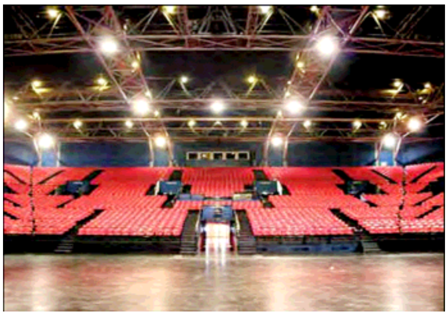
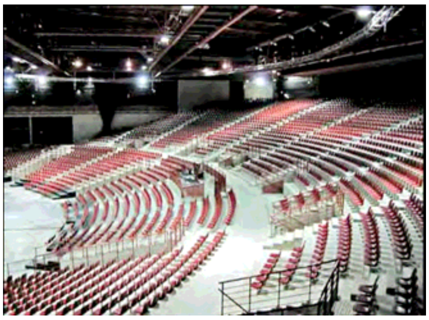




Figure 4. The Zeniths in Orleans, Paris and Dijon (from left to right)

THE HEINEKEN MUSIC HALL [5]

The Heineken Music Hall was realised in 2001. The hall can accommodate an audience of 3,200 seated people, and up to 5,500 when standing. The hall has a rectangular shape, with length 60 m, width 43 m and average height 18.6 m, which results in a volume of 48,000 m³.
To match the required acoustical parameters all the walls are completely covered with broad band absorption with a thickness of 300 mm. To gain additional diffusion at low and mid frequencies, three different material constructions were applied in an alternating pattern at the walls. The ceiling is fully covered with a absorbing construction of 150 mm thickness. Figure 5 presents an overview of the applied materials.

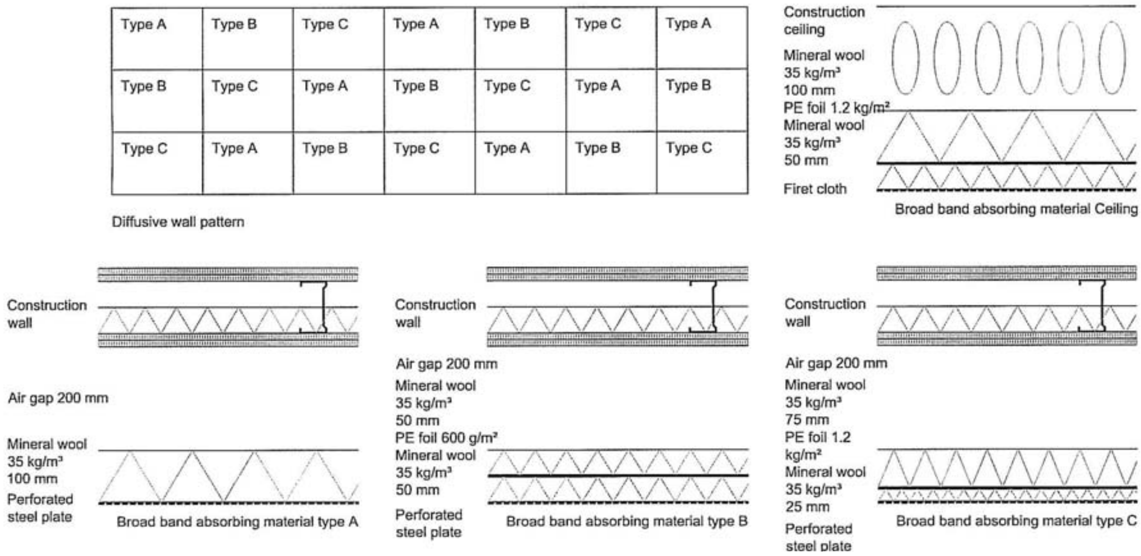


Figure 5. Broad band absorption pattern and materials as applied in the Heineken Music Hall

The material used for the walls did have to be 'audience-proof'. Absorbent materials are usually the opposite. Therefor measurements in the reverberation room were used to determine the influence of a perforated metal sheet wall covering with a perforation degree of 29 %. Up till 1.5 kHz the measurement results show no difference, from 2 to 4 kHz the absorption coefficient is 0.1 to 0.15 less with the perforated wall covering. Due to the metal wall covering the unoccupied hall in empty state is not completely echo free. According to the validation measurements in the unoccupied hall a few positions show a echoic reflection pattern at frequencies above 1.5 kHz. In practice this turned out not to be a problem. During concerts a PA system is used, which has a higher directivity at 1.5 kHz than the omnidirectional source used at the validation measurements. Supplementary the stage wall can be covered with a curtain to eliminate high frequency reflections from this wall, which was shoved aside during the measurements.

The measured reverberation time for the unoccupied hall, presented in figure 6 is extremely low for a volume of 48,000 m³. Also are the measured decay patterns mostly homogenous. The conclusion is that the absorbent material constructions are highly effective. In combination with a decrease of sound of 5.5 dB per doubling of the distance, which is nearly free field condition, and very good measured values of speech intelligibility (Alcons ≤ 10 %) the expectations are completely satisfied. The performing pop group can bring its own sound installation and use it without difficult modifications. After 5 years of pop concerts at the Heineken Music Hall, critics about the acoustics are still very good.

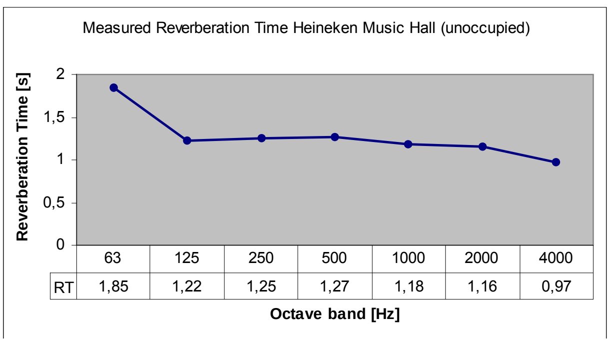


Figure 6. Measured Reverberation Time Heineken Music Hall

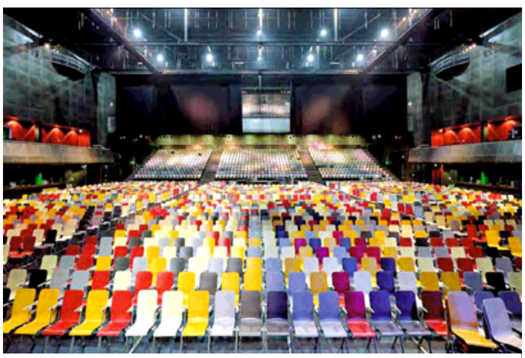


Figure 7. Overview of the Heineken Music Hall

THE AMSTERDAM ARENA

The Amsterdam ArenA was realised in 1996. It is designed as a football stadium with the luxury of a partly transparent roof that can be opened and closed. The stadium has an oval ground floor, steep balconies and a concave ceiling. The length is 150 m at field level to 225 m up the balcony, the width is 95 to 165 m and the height at maximum 53 m, which results in a volume of 1,300,000 m³. Partly because of the roof construction, it turned out to be a suitable accommodation for large scale pop events, unwanted weather conditions can be shut out. The stadium can accommodate 50,000 to 70,000 visitors in concert configuration.

Figure 8. Overview of the ArenA, with the new baffles

But, not being designed for concerts, the stadium became infamous for its acoustics. Although the non-transparent part of the roof was made of sound absorbing material, the measured reverberation time was very long.

In 2005 plans were made to make some adjustments to the ArenA with which it should become more suitable for pop concerts. The first plan was to darken the transparent part of the roof during concerts, and the question was whether it would be possible to combine this with sound absorption. But the wish for darkening disappeared for the moment, and with a concert of the Rolling Stones coming up, the wish for better acoustics became more prominent.
As always, it appeared difficult to design absorbing materials that met all the existing conditions of the building. Alterations at the steep balcony floors and walls were not realistic due to the impact, it would almost mean rebuilding the stadium. The roof was the only available surface for alterations, but because of the grass football field, the impact on the daylight be minimised. Besides, the weight of the absorbing materials should be minimised because of the existing steel roof construction. Baffles seemed to be the most plausible solution.

According to the approximation formula, the preferred reverberation time for the stadium in unoccupied situation would be 3.8 s, which is a lot shorter than the measured average RT of 9.9 s. Although there was not a definite RT that had to be accomplished, the goal of investigation was to search for maximum improvement with a minimum material added.
In Odeon (v3.1) an acoustic model was made, which was validated with the reverberation measurements in the existing stadium. For several situations resulting predictions were calculated. At the same time, laboratory measurements were carried out to optimise different baffle constructions for their absorbent properties, especially at low frequencies and their weight.

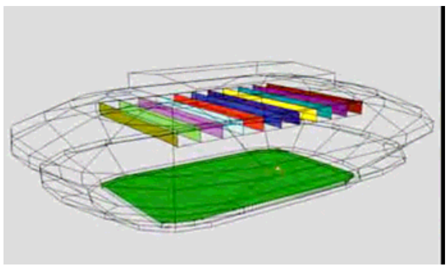


Figure 9. Odeon model of the ArenA

Eventually, a combination of baffles as drawn in figure 10 was preferred:

1. Baffle construction 7 m high under the ‘catwalk’ with total length of 400 m, the baffles can be railed away and stored under the non-transparent part of the roof;
2. Two times nine ‘curtain’ baffles 7 m high 40 m long under the transparent part of the roof transverse to the length of the stadium. These ‘double curtains’ can be lowered down.

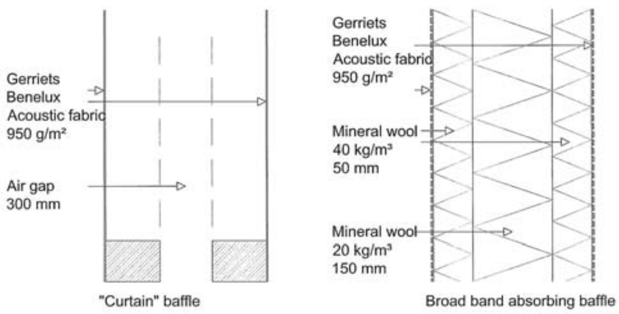
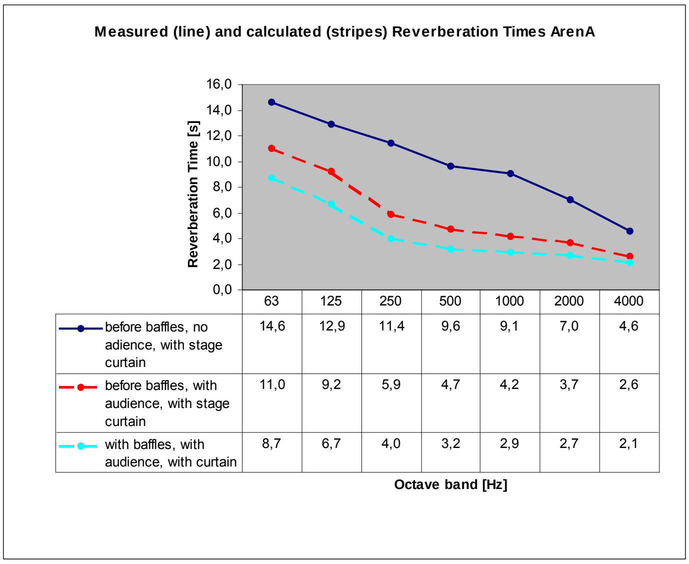


Figure 10. Baffle constructions for the ArenA

The constructive margin for these extra materials is so narrow, that in winter the baffles have to be removed altogether. Their weight can't be added to the weight of possible snow on the roof.
Figure 11 presents measured and calculated reverberation times.

When applying the absorbing materials, also a new loudspeaker system with line arrays was put up. At football games it addresses the public at the seats. For concerts the individual arrays can be turned to be more in the line of the stage clusters. If well adjusted and not too loud, it enhances the clarity for the audience on the balconies.



	63	125	250	500	1000	2000	4000
before baffles, no adience, with stage curtain	14,6	12,9	11,4	9,6	9,1	7,0	4,6
before baffles, with audience, with stage curtain	11,0	9,2	5,9	4,7	4,2	3,7	2,6
with baffles, with audience, with curtain	8,7	6,7	4,0	3,2	2,9	2,7	2,1

Figure 11. Measured (line) and calculated (stripes) RT's ArenA

Compared to the volume of the hall, the area of absorbing materials is very low. It's nevertheless quite efficient due to the position of the baffles. It creates an effective reduction of the acoustical volume and the curved roof is practically out of sight. The optimum effect is reached though if the stage is at the short side of the stadium. A great part of the backwards oriented sound 'beams' from the stage cluster are absorbed at the stage curtain and therefore will not reflect from the rear wall and roof.
Although the acoustics of the ArenA is still not excellent for pop concerts, the improvement, especially in comparison to the area of applied materials, is good. For good acoustics at a concert, it's preferred to have the stage on the short side, and not on the long side or in the middle. The curtain baffles are much more efficient in the direction perpendicular tot the sound. Also the combination of stage clusters with the arrays is better with the stage on the short side. Because the main system is brought in by the playing band, the combination of loudspeakers clusters with the line arrays must always be conscientiously set up, and that takes time and effort, which is of course not ideal for the technicians to work with.

CONCLUSION

Designing large halls for indoor pop music is a room acoustical challenge. The music is reproduced through electro-acoustic systems, therefore a high direct-to-reverberation ratio is to be aimed at for good definition. Because of the large dimensions, the delay between direct sound en the first-order reflections is significant and reflections may be heard as echo's if they're too strong. A 10 dB suppression of such reflections, also for low frequencies, is a necessity and can be accomplished by the use of broad band absorbing materials, which can consist of different material layers. The matched approximation formula, $T_{60}=0.038V^{0.325}$, can be used as rough guidance for a room acoustic requirement in the early stage of the design for a large indoor pop accommodation. Some practical solutions to match te requirements are presented in this paper.

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