DIFFUSIVITY AND ITS SIGNIFICANCE TO EFFECTIVE SEAT ABSORPTION IN CONCERT HALLS

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1 INTRODUCTION

In concert halls, the seats are normally the dominant sound absorber. Since this absorber is not evenly distributed in all directions, the reverberant sound field can not be assumed to be diffuse. The overall geometry combined with surface diffusion affects how effectively the seats absorb the reverberant sound. A room with high, parallel side walls with little surface diffusion will allow sound to linger longer in the upper volume of the hall, than if course geometry and rough surfaces forces more of the sound to be “kicked down” into the absorbing seating area. Moreover, seat absorption coefficients measured in laboratory are generally not equal to those measured with the same seats during installation in a new hall. These effects can to some degree of accuracy be demonstrated with room acoustic simulation software. This paper points at some practical difficulties and presents an approach to avoid some unpleasant surprises in concert hall planning.

2 EFFECTIVENESS OF ABSORPTION

The effect on reverberant sound from a given amount of absorption depends on the room acoustical diffusivity of a room.

The sound absorption area from an absorbent can be measured in a reverberation room, calculated from reverberation times according to ISO 354[1]. It is established that for the same amount of absorbing material introduced in a room, the effective absorption depends on the amount of diffusion in the room, and if the diffusion is insufficient, it depends on the actual location of the absorbing material. According to ISO 354 Annex A, the optimum measurement condition can be found by increasing the amount of diffusivity until a constant (diffusivity-independent) absorption value is achieved. However, when doing this exercise by simulating a test room (satisfying ISO 354 requirements) in the ODEON 8.5 software, a diffusion-independent absorption can hardly be achieved and the optimum amount of diffusion can not be determined without considerable uncertainties. In real rooms, like concert halls and other performance spaces, the diffusivity conditions may differ significantly from the ones in the laboratory where the seat absorption is measured, not to mention differences from one hall to another.

3 DEPENDENCIES AND UNCERTAINTIES

When a performance space or other room dependent on acoustics is to be designed, it is of great value to have reliable methods for predicting the reverberant sound. Needless to say, building costs are high, and corrections are also expensive—if possible. The diffusivity-dependent absorption effectiveness stated above represents uncertainties that can effect predictions of reverberant sound:

- Uncertainties in measured absorption coefficients
- Uncertainties associated with diffusivity of the actual space

Both uncertainties can be seen the example in Figure 1. The diagram shows the results from a test of diffusivity according to laboratory measurement standard ISO 354 Annex A.2., simulated with the ODEON 8.5 software. 100% absorption represents the theoretical (input) value of the measured object, namely a 10sqm sample of absorption coefficient equal to 0.90. The results are average of octave bands 500Hz through 4kHz according to the ISO 354. Therefore, the frequency dependency is hidden.

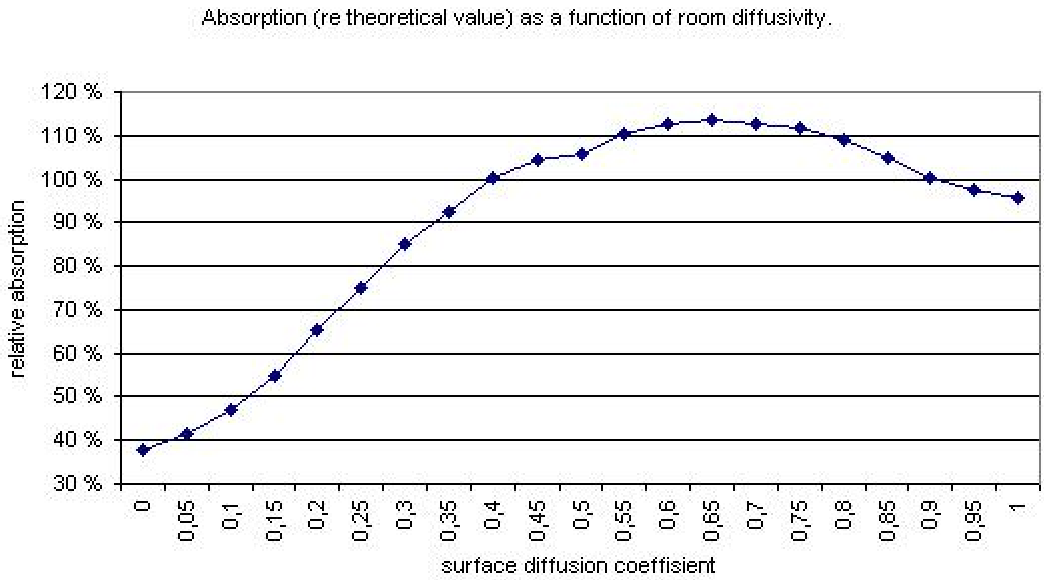

Figure 1

3.1.1 Uncertainty in measured absorption coefficient

The first uncertainty is that effective absorption does not approach a constant value as diffusivity increases. Rather, it seems to fluctuate between 100% and 114% for surface diffusion coefficients from 0.40 and upwards.
The second uncertainty lies within the fact that the effective absorption is so sensitive to diffusivity. Specifically, the absorption increases from 45% to 65% as diffusion increases from 0.10 to 0.20 and from 65% to 100% as diffusion increases from 0.20 to 0.40. If diffusion exceeds 0.40, the effective absorption exceeds the theoretical value. This means that the effect of seats measured in the average laboratory will be underestimated if they were installed in a performance space with surface diffusion in the range 0.40—0.90, and overestimated if surface diffusion was less than 0.40. For example, with surface diffusion less than 0.20, the effective absorption will be less than 65% of the average laboratory value.

3.1.2 Uncertainty in predicting diffusion properties

Also, there are uncertainties associated with predicting the actual surface diffusion of an existing hall or a planned hall based on geometrical properties alone. The same goes for the task of aiming to design and build a surface with surface diffusion 0.40, since reaching only 0.30 diffusion results in 15% less effective absorption.
Seats installed in rectangular halls with large plane wall surfaces in the upper volume have less absorption effect than if installed in a nonrectangular space where reverberant sound is directed more into the seating area than in the case of the rectangular halls. Beranek's seating absorption data are separated into these two categories of halls [2].
Figure 2 shows one example of how the predicted RT's in different octave bands may depend on upper wall surface scattering in one case of a 1200 seat rectangular hall with volume of approx. 15.000 cubic meter. The higher octave bands are more sensitive to increased surface scattering, as can be expected: More scattering on vertical surfaces will redirect more sound down into the audience area, and audience areas are effective high frequency absorbers. On the other hand, to

make a 5% difference—a Just Noticeable Difference JND– the scattering needs to increase from the reference value of 0.15 to the rather high scattering value of 0.70.

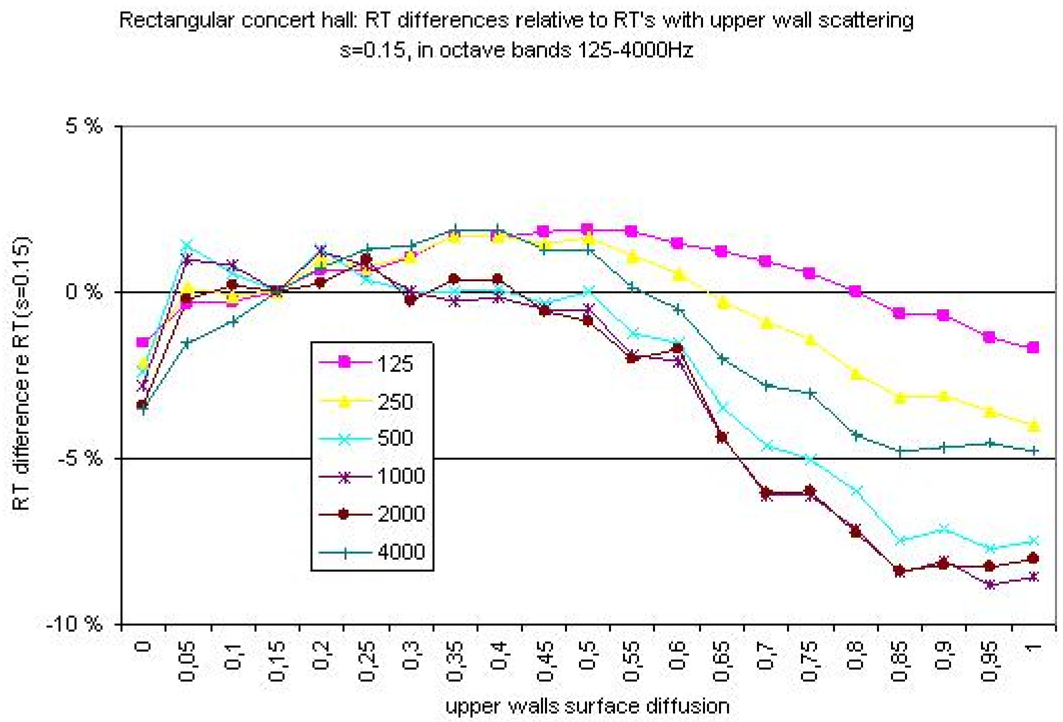

Figure 2

The results in Figure 2 may indicate that the uncertainty related to surface diffusion of the upper walls in a rectangular concert hall can be rather small in some cases. However, the overall degree of diffuseness in a concert hall also depends on the surfaces of the ceiling, the floor and the lower part of the walls, in addition to the course geometry of the hall (parallel walls, non-parallel walls, height and width ratios, balconies, etc.), together with the fact that the main absorption (seating area) is concentrated on the floor surfaces rather then well distributed. Therefore, it is far from certain that the seat absorption has the same effect in the concert hall as in the laboratory where they were tested, as we pursue in the following:

3.1.3 From laboratory to hall

Figure 3 shows the effective absorption of the 1200 seats when installed in the 15.000 cubic meter concert hall. Each octave band percentage is the ratio of the seat absorption coefficient obtained by using the concert hall as a reverberation room, to the seat absorption coefficient obtained in the laboratory. Surface diffusion coefficient of the upper walls surrounding the hall is 0.15. The diagram illustrates that the laboratory tests overestimates the seat absorption in this case. When the seats are "installed" in the concert hall, the effective absorption at 125Hz is only 84% of the value from the laboratory test. One explanation for this is that the overall diffuseness at low frequencies in the rectangular concert hall is less than in the laboratory, allowing sound to linger longer in the upper volume rather than being exposed to the sound-absorption seating areas at floor level. At 125Hz the RT was 2.4 s, seat a was 0.68 in lab and 0.57 in-situ, while the ODEON input a was 0.60.

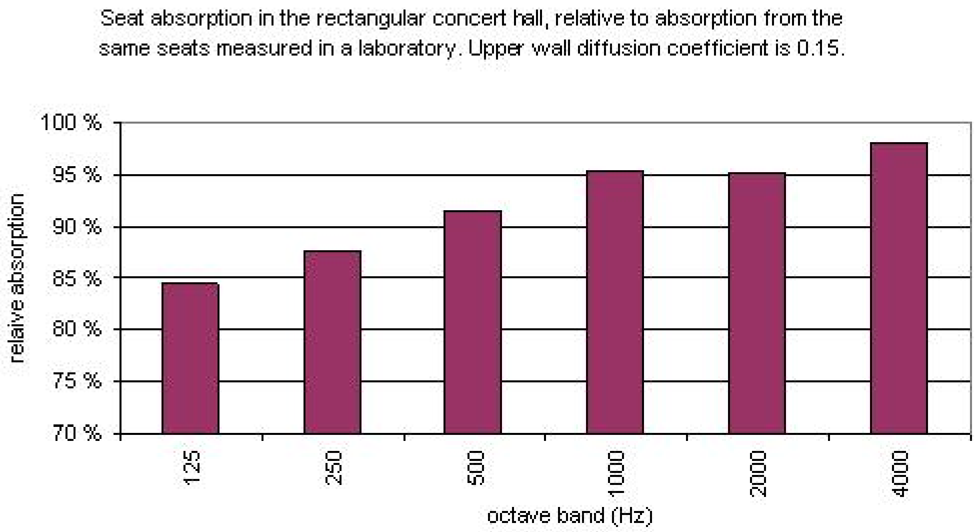

Figure 3

4 REAL MEASUREMENTS VS COMPUTER SIMULATIONS

All the results above are obtained from simulated “measurements” in ODEON 8.5. One may object that these are not real measurements. Evidently, prediction tools come with a certain degree of uncertainty. On the other hand, some uncertainties regarding how well ODEON simulates sound are cancelled out by studying the ratio between two simulations. Besides, over the years there have been several reports on surprising differences between chair absorption data from lab-tests and data obtained when installing the chairs in the actual concert hall, similar to the results above.

Simulated results deviate more or less from real results, and thus have inherent uncertainties. But there are uncertainties associated with real results too, and the so called reproducibility of the lab test method is still under investigation. Absorption data obtained from one real lab test deviate more or less from the average results from all real test labs. This means that uncertainties cannot be eliminated; only statistically controlled.

Testing of concert hall chairs in a test lab is in practice a prediction method, even though it seldom is referred to as such. On the contrary, it is common to distinguish between predictions and measurements. However, the purpose of the seat absorption test is to predict whether or not the seat type is proper for the actual hall. This prediction method is based on the assumption that once we know how the seats affect one room (e.g. a test lab), we can tell how they affect another room (e.g. a concert hall). A similar prediction method will be to use experience of how one hall responds to seat absorption to predict how another hall responds to seat absorption. Regardless of prediction method – experience, measurements, or simulations – one has to take the differences in diffusivity conditions into account.

Rather than asking if we can trust computer simulations, we should discuss how we can reduce the inherent uncertainties of our prediction methods. One way of taking diffusivity conditions into account is by computer simulations as presented in this paper. Another way is the statistical approach by Beranek. The approach implies in practice that seats are tested with existing concert halls as test rooms, separated in the categories rectangular halls and non-rectangular halls. It could be extended by including at least test laboratories, and maybe by dividing non-rectangular rooms into proper sub-categories based on prominent, unambiguous features. However, the statistical significance of the hall categories should be verified. A drawback with this approach is that many halls will be difficult to categorise, especially the unique hall that many architects and clients will strive for. As an alternative, computer simulations will be less conservative and has more to offer in the more innovative projects.

5 RECOMMENDATIONS

5.1 General

The demonstrations above point at the fact that the overall diffusivity in a room can strongly affect the effective absorption coefficients, in lab tests as well as in-situ, and that this should be taken into account during the planning of concert halls and other reverberant performance spaces when trying to predict the acoustics where seating areas dominates the acoustics. One should keep in mind that when installing seats in a highly reverberant room (e.g. a concert hall or a test-lab), not only absorption is being introduced, but the diffusivity and thereby the absorption effectiveness is being altered.
As mentioned before, Beranek has separated his seat absorption data in the two categories “rectangular halls” and “non-rectangular halls”, which is an important first step to take the overall diffusivity into account. One might add that lab-test data should always be kept in proper separate categories—never mixed with in-situ data. Neither should lab-test data be applied directly as absorption coefficients in ODEON and other prediction software without further considerations.

5.2 In particular

Based on the results above, the following advice is meant to prevent some unpleasant surprises in future concert hall planning:

- Predict the absorption effectiveness of the seating area (Figure 3)
- Predict the sensitivity to diffusion coefficient on large surfaces (Figure 2)
- The sensitivity of absorption related to diffusivity in the laboratory test room should be studied further. In the future, curves like the one in Figure 1, for each octave band, should be demanded as part of the documentation from the lab.

Since surprises regarding low frequency reverberation times have been reported, and since low frequency corrections are very difficult to make, the laboratory tests of seats should be performed in a room where the diffusivity requirements includes the important octaves below 500Hz. The octave range 500-4000Hz according to ISO 354 is not sufficient.

5.3 Computer simulation process

Whenever the concert hall design is supported by prediction tools like Odeon, CATT or other tools taking surface diffusion and 3-dimensional reverberant field into account, the simulation programme should be extended to include the seat tests in the laboratory. This can be done by simulating the test measurements in a computer model of a test lab that meets the test criteria, e.g. ISO 354 but including the proper low frequency diffusivity requirement. After having achieved satisfactory predictions from the concert hall simulation, the seat properties in the concert hall model should be applied to the seats in the test lab model, and the absorption coefficients calculated according to ISO 354 based on RT’s from the test lab simulations. When it comes to the real seat test, the absorption coefficients from the real test lab measurements should be compared with the absorption coefficients from the simulated lab measurements, rather than with the input alpha’s in the computer model. To be specific, one should not compare real lab test results with the input alpha’s in the computer model if one wants to reduce uncertainties as much as possible.

6 CONCLUSION

Different rooms have different diffusivity. Therefore, one and the same absorbing surface, e.g. concert hall seats, will in general have different effective absorption coefficients. We have to deal with three different sets of absorptions coefficients when predicting acoustics, namely the input coefficients in the prediction algorithm, the lab-test coefficients, and the in-situ coefficients.

A sound absorbing object does not have absolute absorption coefficients. There exists only relative absorption coefficients, related to the measuring conditions, whether in different laboratories, or in different halls as measured in-situ. This paper suggests a method to predict the relation between absorption coefficients. In concert hall planning this method can be used to take diffuse field differences between laboratory and a concert hall into account.

7 REFERENCES

1. Acoustics – Measurement of sound absorption in a reverberation room, ISO 354
2. Analysis of Sabine and Eyring equations and their application to concert hall audience and chair absorption, J. Acoust. Soc. Am. 120 _3_, September 2006