AUDITORIUM ACOUSTICS: A CASE STUDY

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ABSTRACT

In the new, recently built, headquarters of Kaupþing Bank a 178 seat auditorium was carefully designed. An acoustic model of the auditorium was made in CATT-Acoustic and measurements were made with WinMLS2004 after the opening for comparison. A reasonable agreement was found between the measured and modeled results.

1. INTRODUCTION

1.1. An overview of the design

The aim of the acoustical design of the auditorium was to design a hall that could easily be used for lectures without a sound reinforcement system. The speech intelligibility should be sufficiently high along with evenly distributed SPL from a source on the stage throughout the audience area.

The acoustical treatment of the hall was following: the side walls were made diffusive to avoid flutter echo, a sound reflector was placed in the ceiling to increase the SPL in the rear part the audience area and then sound absorption was placed in the circumference of the audience area to adjust the reverberation time.

Technical details of the auditorium are given below:

Length, L	16,6 m	Seating capacity, N	178
Width, W	12 m	Seating area, Sa	123 m^2
Heigth, H	6,1 m	Sa/N	0,7 m^2
Volume, V	915 m^3	V/N	5,1 m^3

Appropriate reverberation time for an auditorium of this size is $T30_{500}$ = 0,9 sec [1].

The acoustical design of the side wall went through two phases. In the early stage of the project the acousticians suggested that the side wall should be covered with reflectors that would be tilted in order to direct the sound waves, travelling from the stage, down towards the back of the audience area. This idea developed for some time until the architect requested another treatment on the side walls due to aesthetic reasons.

In the second phase it was suggested that the walls would be treated with diffusive surface instead of being covered with reflectors. For this purpose MLS-diffusers were used although being band limited compared to other types of diffusers. The diffusive form was based on an MLS-diffuser with the period 7. The MLS-diffuser is only effective over an octave so the design frequency was set to 800 Hz with the effective frequency range 560 – 1120 Hz. The dimensions for each well is 10,75 cm deep and up to 21,5 cm wide [2]. The MLS-diffuser described was used as a starting point for the architectural design of the final wall. The architect was given the freedom to play the MLS-sequence, i.e. shift it, reverse it etc. as long as the pattern within each period was maintained. The front side of the diffusers is made of 6 mm painted MDF.

In the ceiling above the audience area is a reflector. It is 8,5 m wide, 2,3 m deep and rotated by 12° along the transverse axis. It directs sound waves travelling from the stage towards the rear of the seating area.

It was required by the acousticians that the seats in the audience area would have minimal difference in sound absorption whether they are occupied or not. The seating area is 113 m^2 and each seat is upholstered and covered with leather. Sound absorption data for the seats can be seen in figure 1.

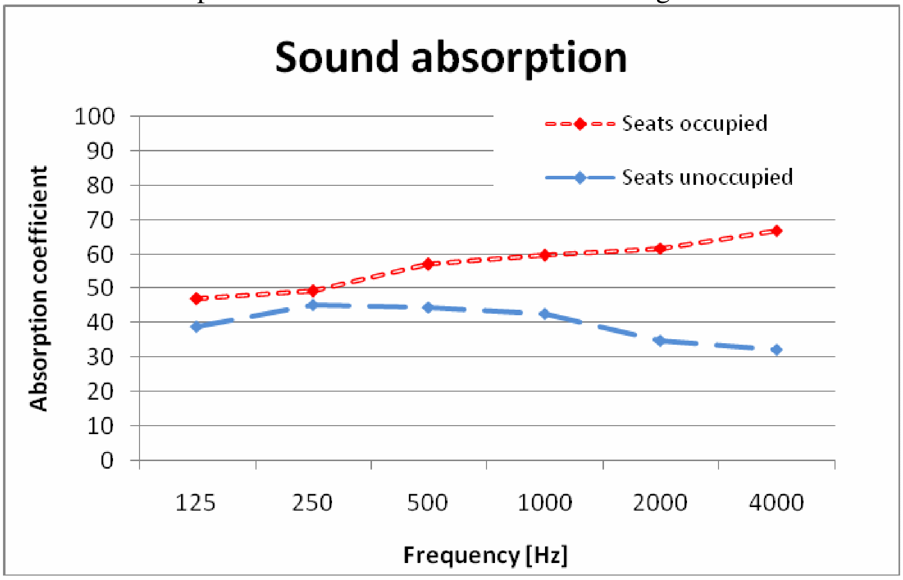

Figure 1 *Sound absorption data for audience seats, data received from the manufacturer.*

The necessary additional sound absorption is located in the ceiling. It is made of perforated gypsum board with 18% perforation. The boards have a thin sound absorbing fabric glued on the back side and behind them is a cavity more than 20 cm deep. The area of sound absorption is 95 m^2 which is equivalent to 42 % of the total ceiling area.

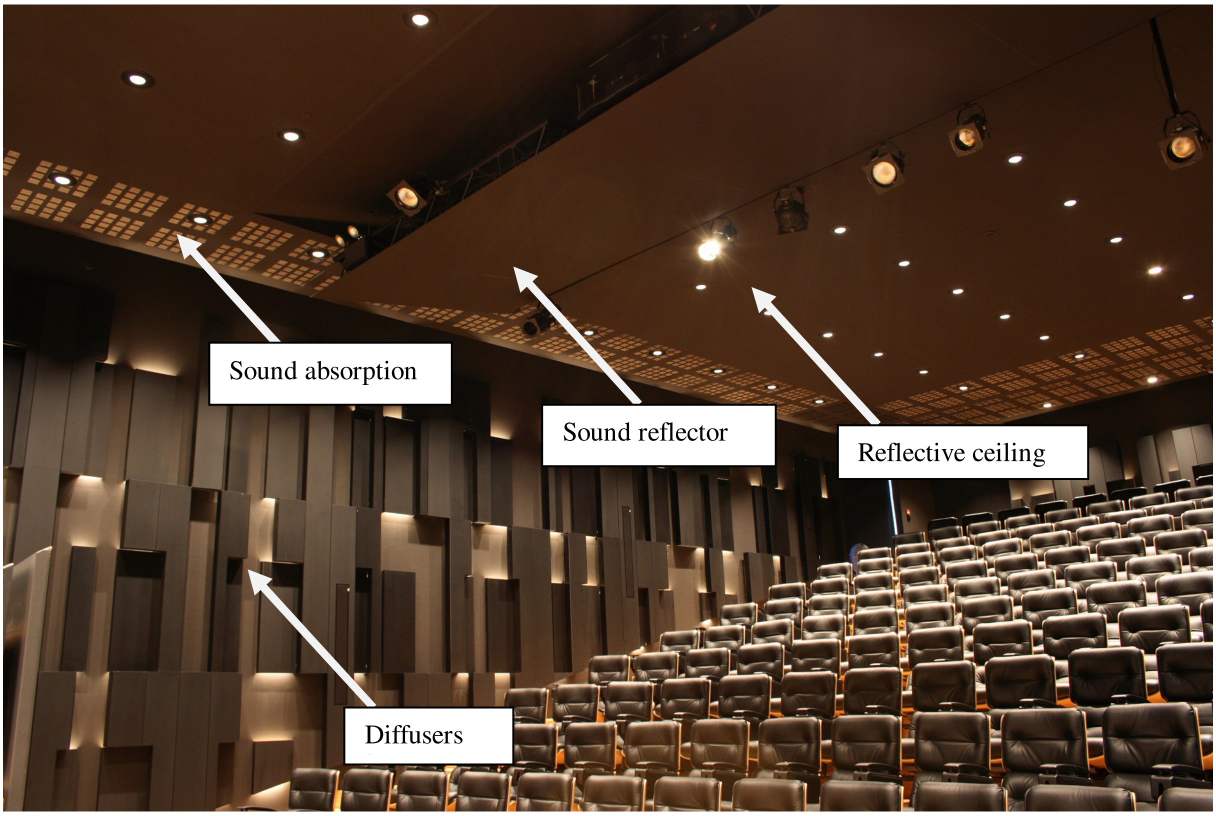

Figure 2 *A view inside the finished auditorium*

1.2. Computer simulation

A computer model of the auditorium was made in CATT-Acoustics (www.catt.se). The program was used to estimate the amount of additional sound absorption necessary to reach an appropriate reverberation time of 0,9 sec. The sound absorption data for specific materials such as perforated gypsum boards and the audience chairs was based on information given by the relative manufacturer. The sound absorption data used for other surfaces were taken from common databases.

The modeling of the side walls was done in a simplified way. Each panel on the diffusive walls was not modeled as such but instead the whole wall was modeled as a single element with the frequency dependent scattering adjusted to an appropriate level. A rendering from the CATT model can be seen in figure 3. Four receiver positions were used for comparison with measurements. The receiver locations can be seen in figure 4.

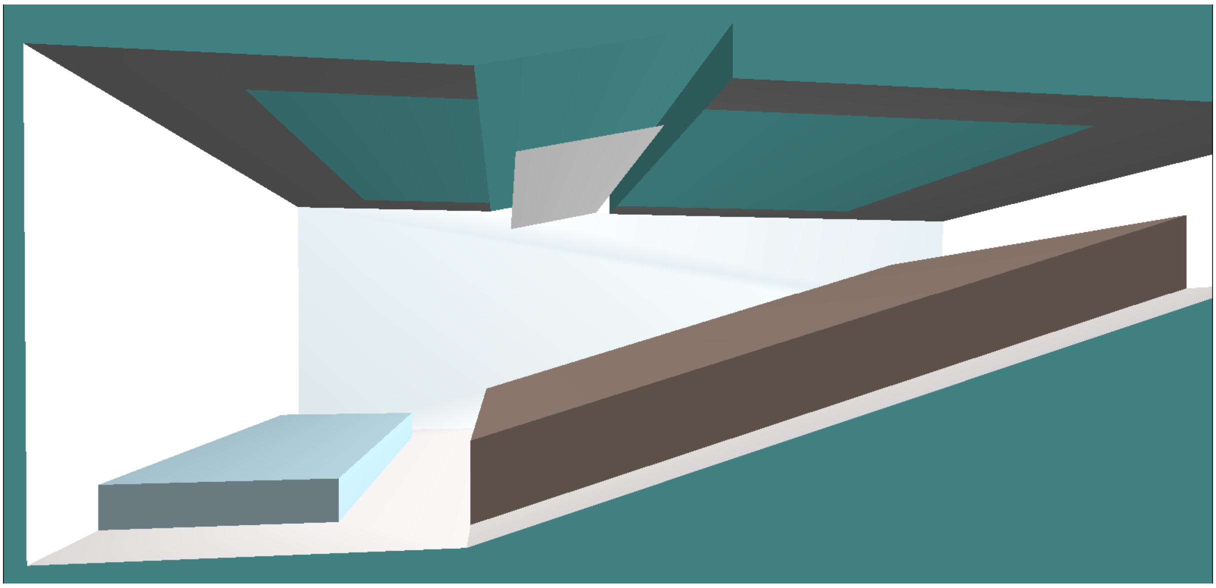

Figure 3 *A rendering from the CATT model.*

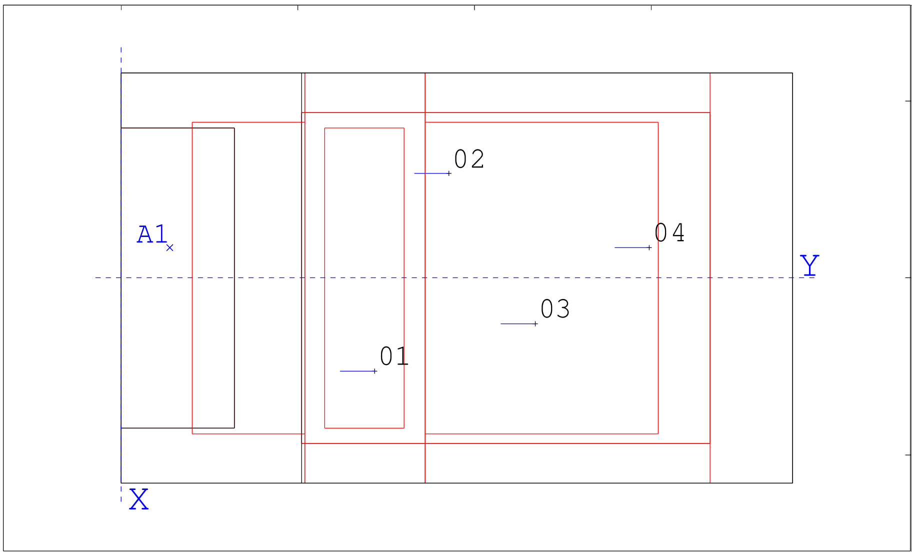

Figure 4 *Source-receiver locations used in the computer model. The same numbering and locations were used for the measurements.*

An overview of the predicted results for the four receiver positions can be seen below for an occupied audience area:

$T30_{500}$	0,8 sec
EDT_{500}	0,7-0,8 sec
$D50_{500}$	59 - 67 %
RASTI	0.63 – 0.68

In figure 5 - figure 7 the results from the computer model can be found. These results are for an unoccupied hall as and are also shown later in comparison with measurements, see figure 11 - figure 22.

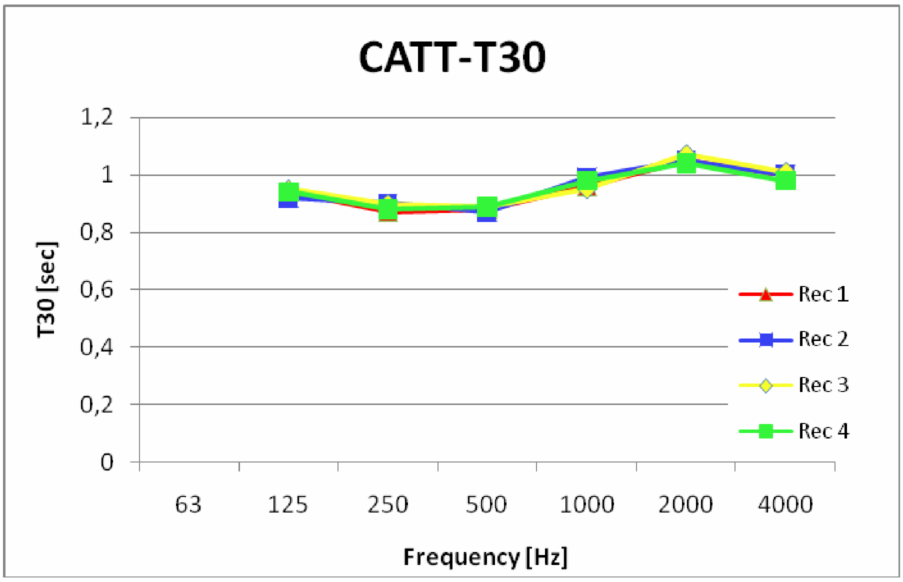

Figure 5 *Predicted T30 for all four receiver positions.*

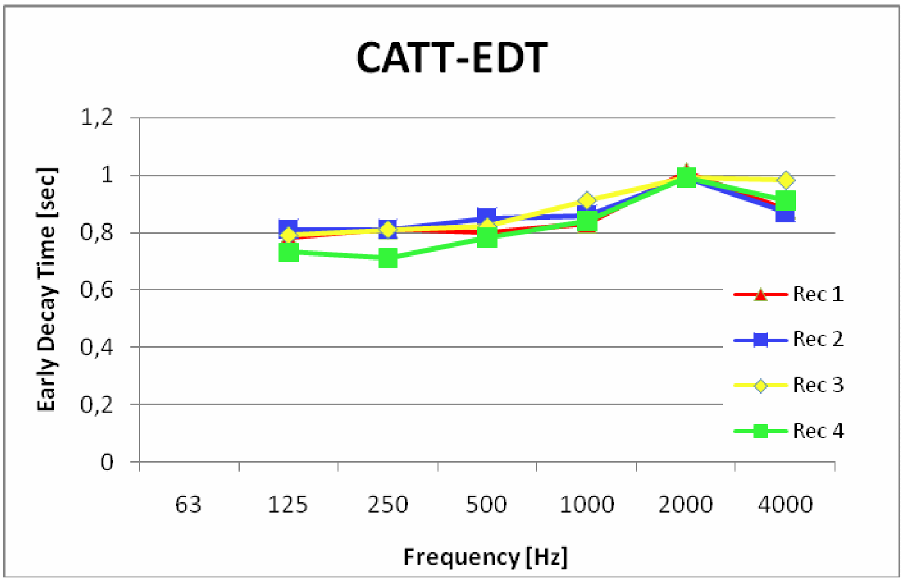

Figure 6 *Predicted EDT for all four receiver positions.*

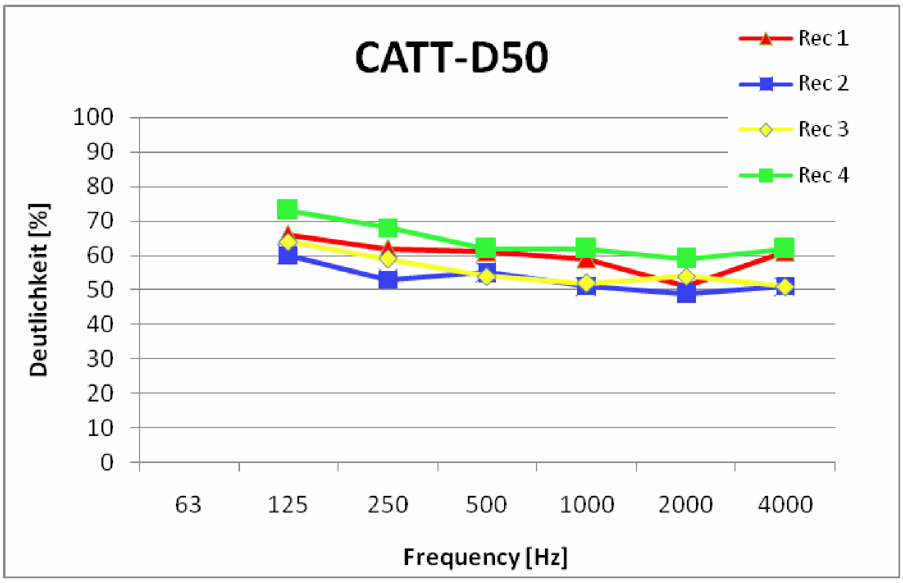

Figure 7 *Predicted D50 for all four receiver positions.*

1.3. Measurements

Measurements were carried out in the auditorium several months after it was taken in use. The measurement system consisted of a portable PC running WinMLS2004 (www.winmls.com), external sound card (Edirol UA-25), microphone (BSWA MP201) and a dodecahedron loudspeaker. The measurements were done according to the standard EN ISO 3382:2000. During the measurements the seating area of the auditorium was unoccupied. The measurements were done using 2 source positions and 4 receiver position. The measurement signal used was a swept sine type. Measurement results for one source and all receiver positions are shown in figure 8 - figure 10.

It can be seen in figure 8 that the measured reverberation time, T30, is consistent through the receiver positions for frequencies around 250 Hz and above. For the frequency range 250 – 4k Hz the reverberation time is measured lowest 0,8 sec at 250 Hz and highest 1,1 sec around 2k Hz.

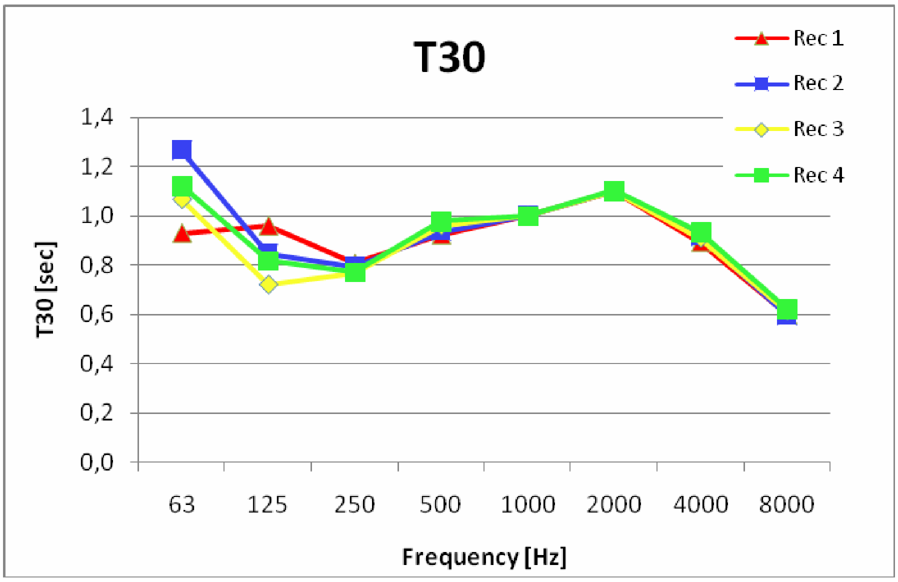

Figure 8 *Measured reverberation time T30, at different receiver points in the audience area.*

As with the measued T30 the measured EDT varies between frequency bands. These variations are most visible close to the stage (receiver positions 1 and 2) where the EDT is measured lowest around 0,5 sec at 125 Hz and highest about 1,1 sec at 2 kHz. This can be seen in figure 9.

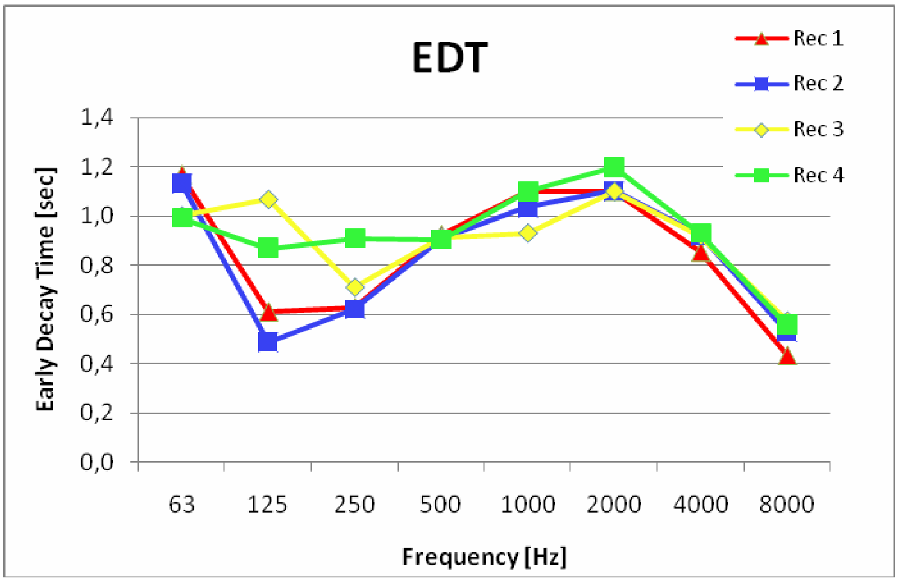

Figure 9 *Measured early decay time EDT, at different positions in the audience area.*

The measured D50 can be seen in figure 10. It can be seen there that the D50 varies between the values 44 – 59 for the three octaves 500 – 2000 Hz for all receiver positions. In the low frequency region the D50 varies considerably between measurement positions.

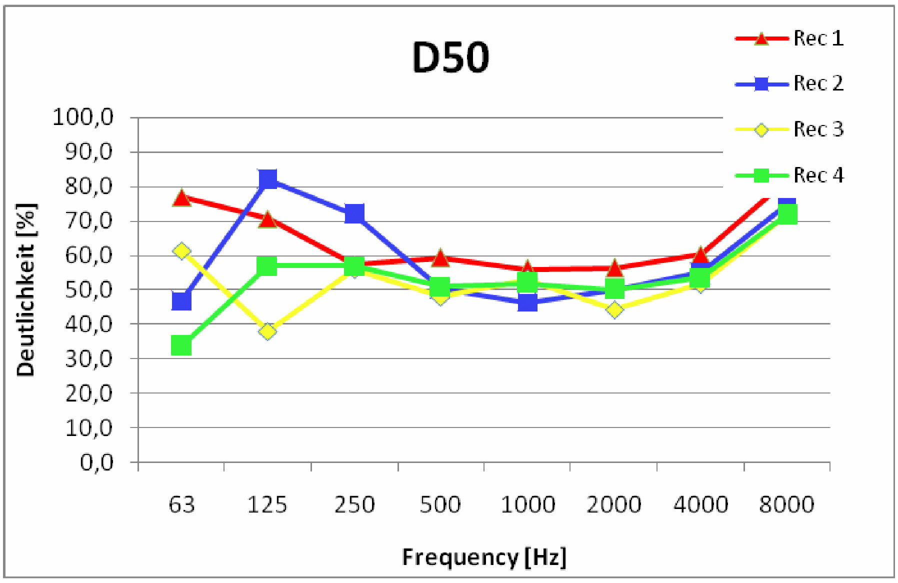

Figure 10 *Measured Deutlichkeit D50, at different positions in the audience area.*

1.4. Comparison of predicted and measured results.

A comparison between the measured results and the CATT prediction can be found in figure 11 to figure 22. In the figures three parameters are shown; T30, EDT and D50. Generally a reasonably good agreement can be found between the measured the predicted results. The agreement is best for the T30 parameter. For the frequency range 500-2000 Hz the reverberation time T30 and EDT are predicted lower than measured and the D50 is predicted higher than measured. The amount of this difference between the measured and predicted results varies between the receiver positions.

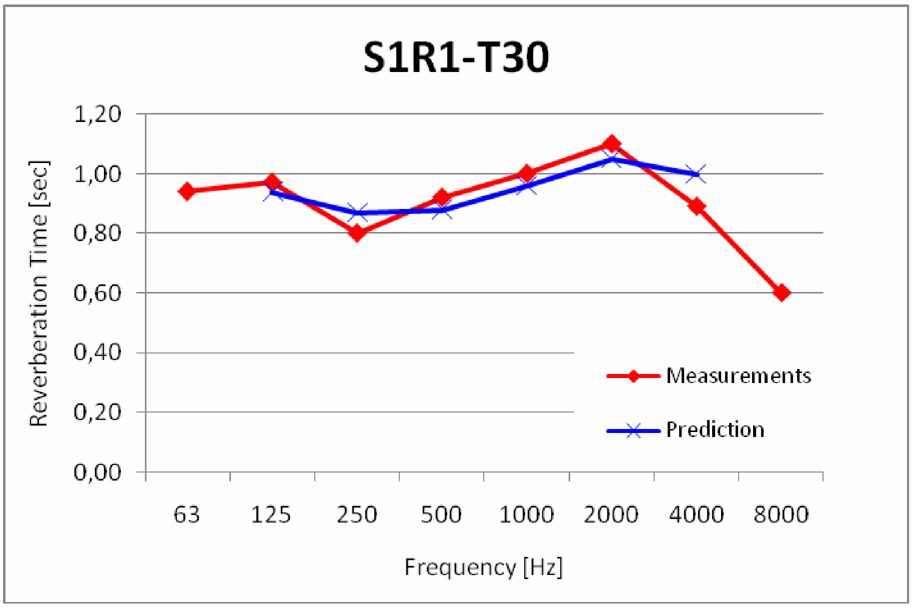

Figure 11 *A comparison measured and predicted reverberation time for receiver position 1.*

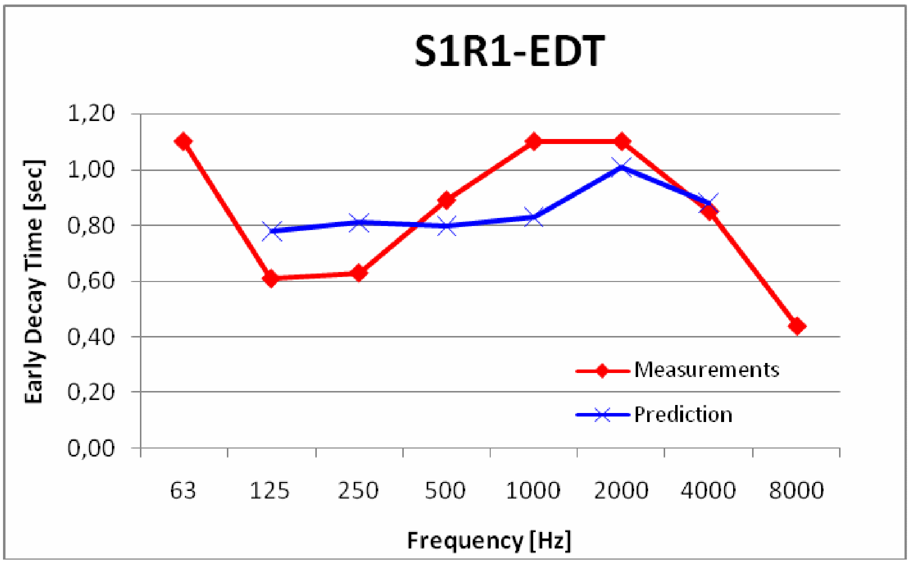

Figure 12 *A comparison measured and predicted early decay time for receiver position 1.*

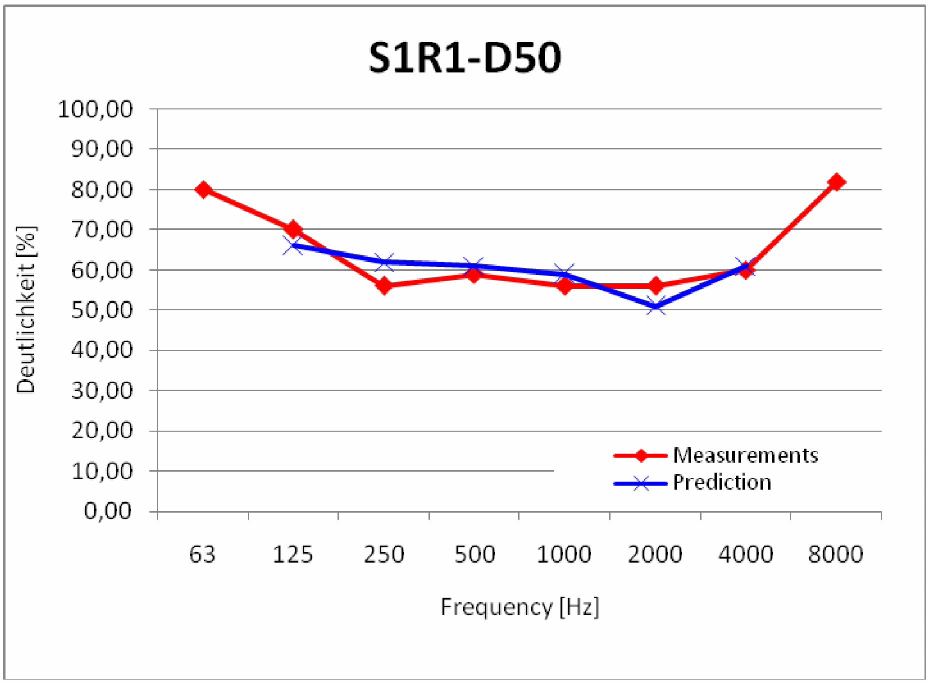

Figure 13 *A comparison measured and predicted Deutlichkeit for receiver position 1.*

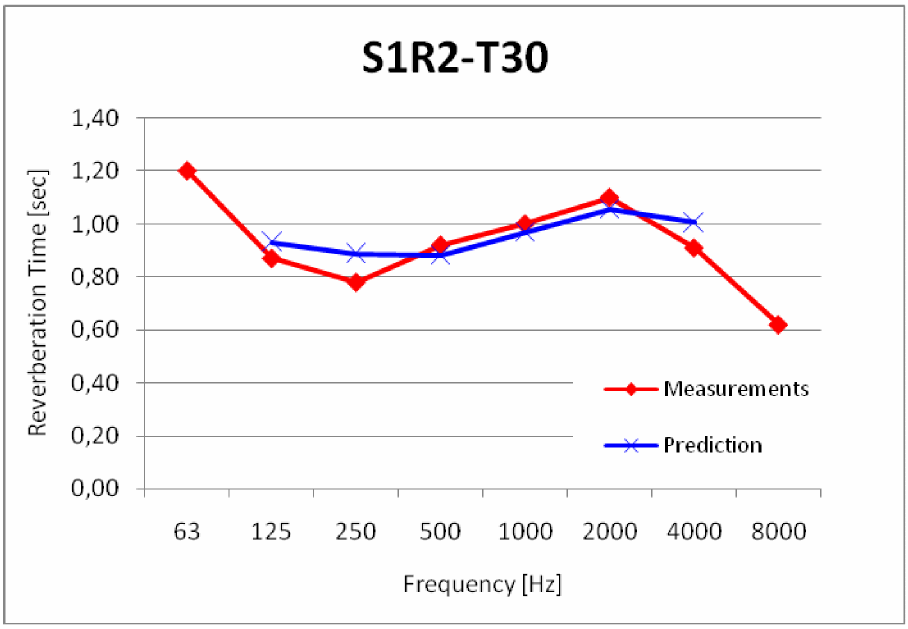

Figure 14 *A comparison measured and predicted reverberation time for receiver position 2.*

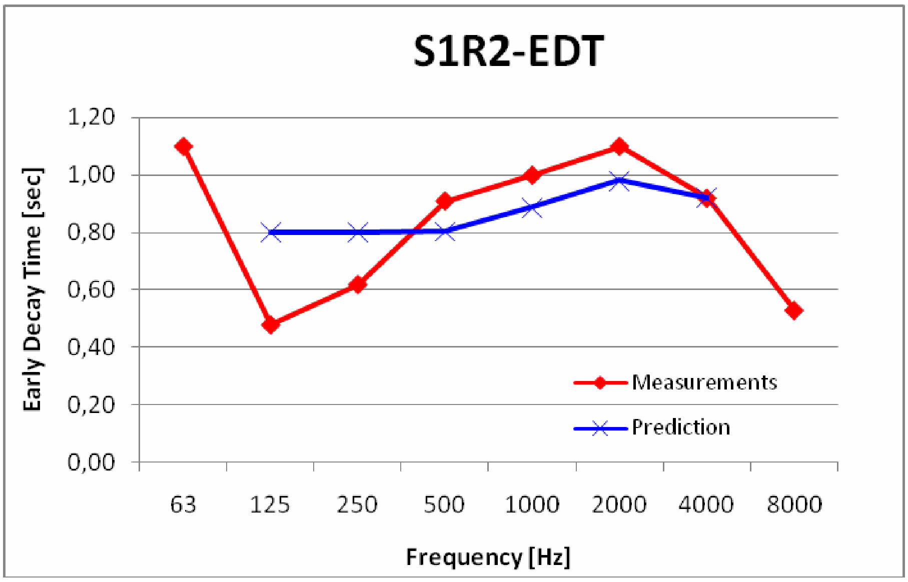

Figure 15 *A comparison measured and predicted early decay time for receiver position 2.*

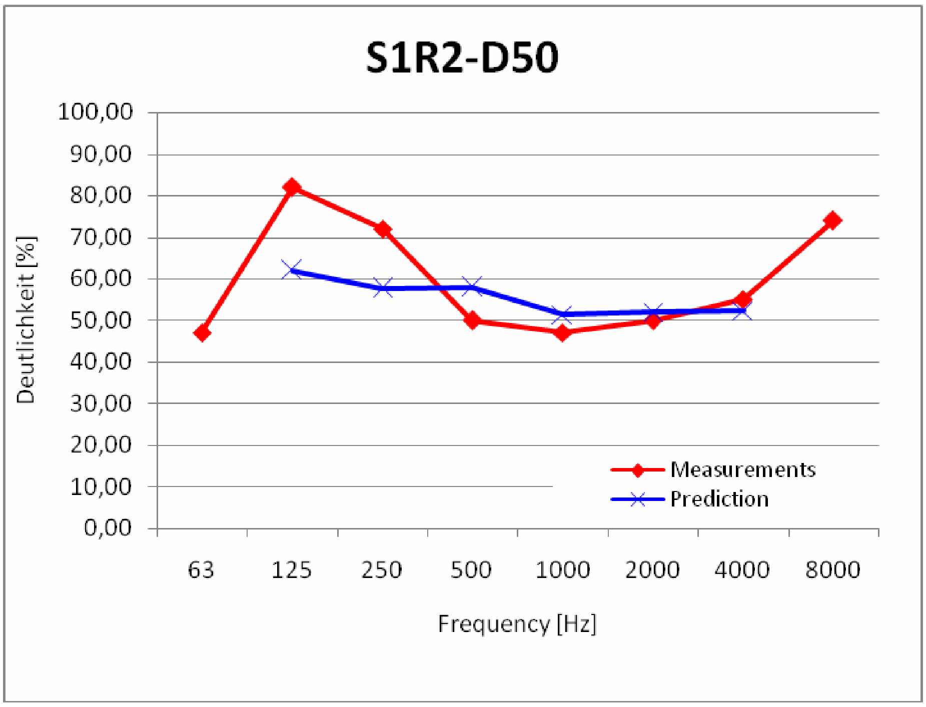

Figure 16 *A comparison measured and predicted Deutlichkeit for receiver position 2.*

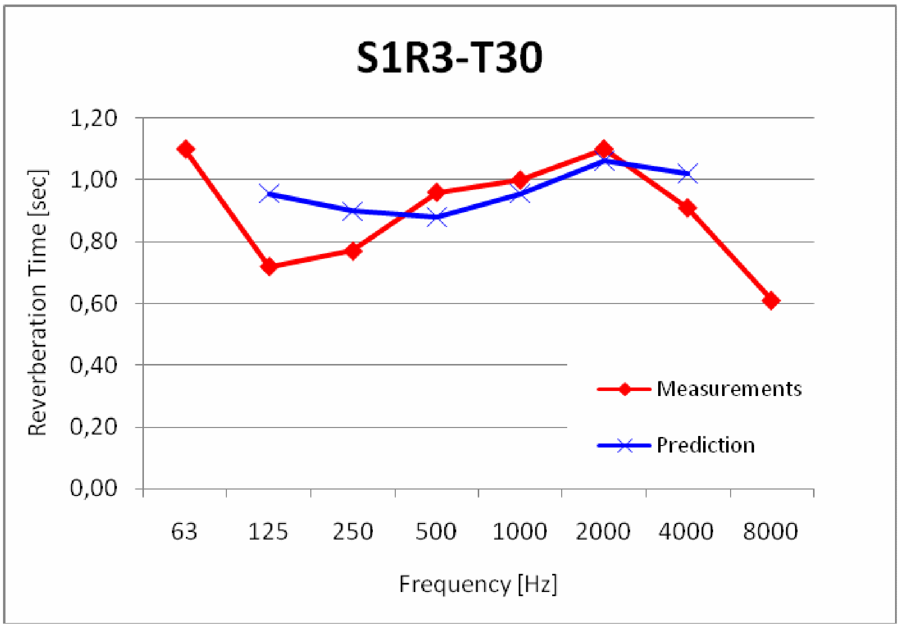

Figure 17 *A comparison measured and predicted reverberation time for receiver position 3.*

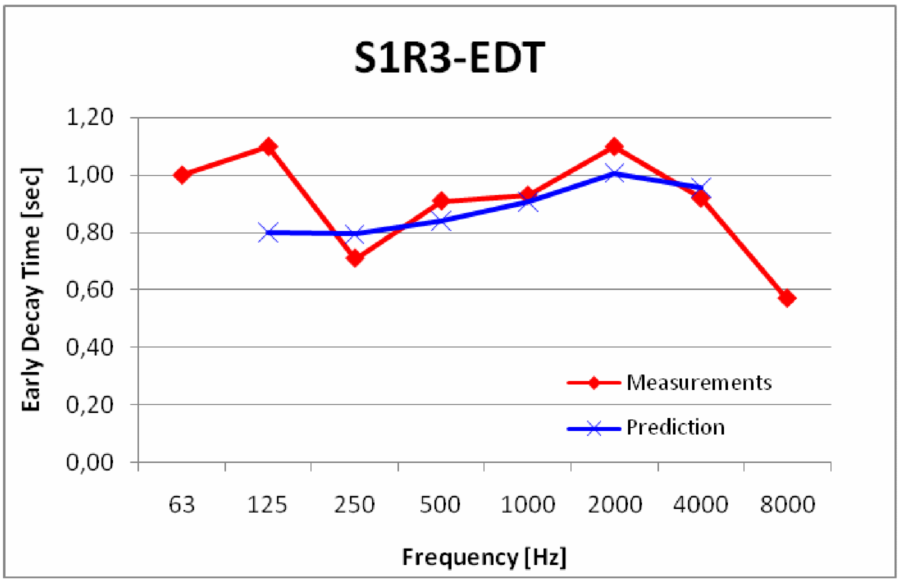

Figure 18 *A comparison measured and predicted early decay time for receiver position 3.*

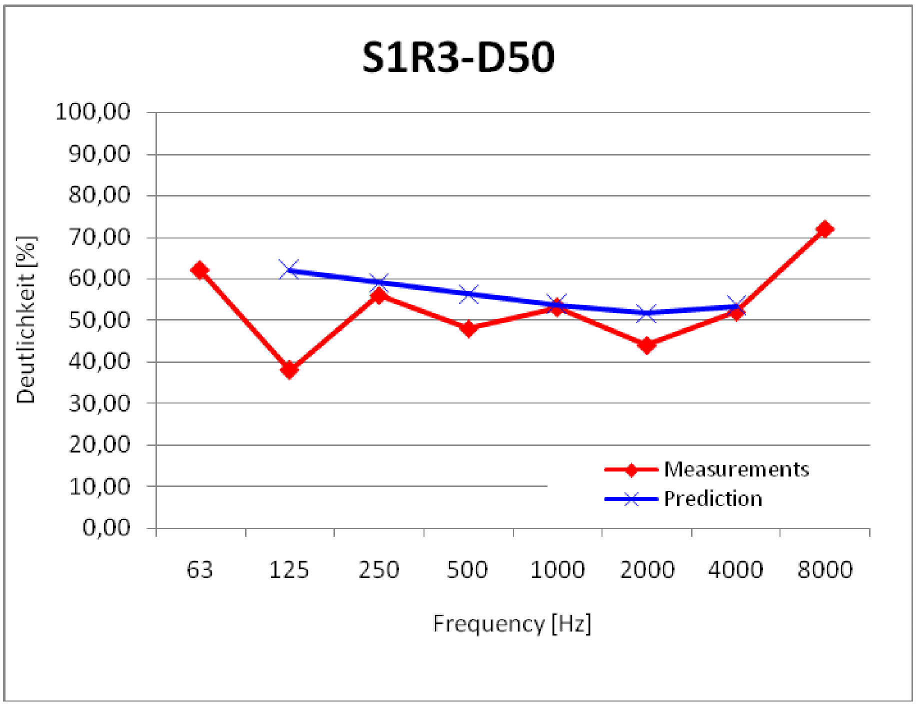

Figure 19 *A comparison measured and predicted Deutlichkeit for receiver position 3.*

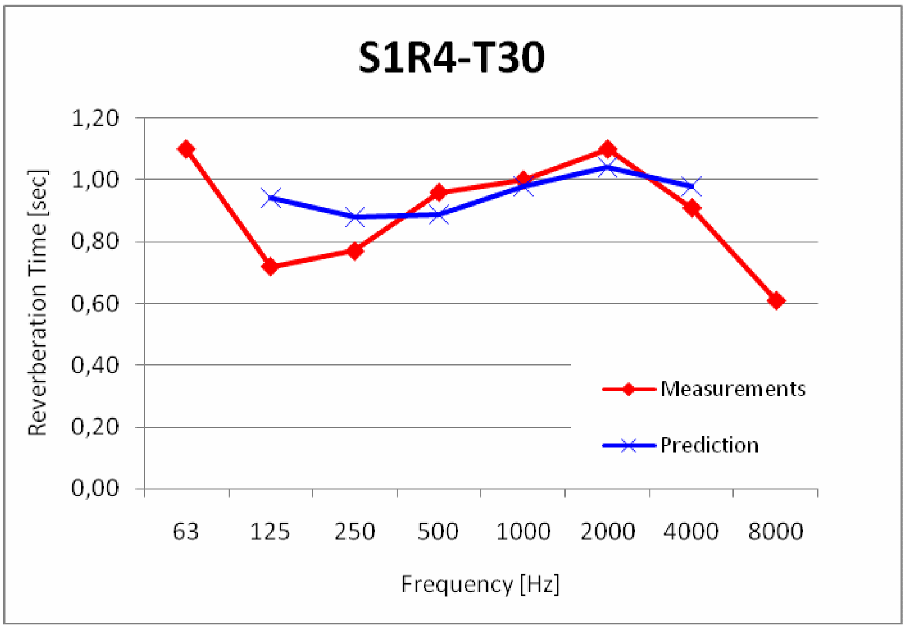

Figure 20 *A comparison measured and predicted reverberation time for receiver position 4.*

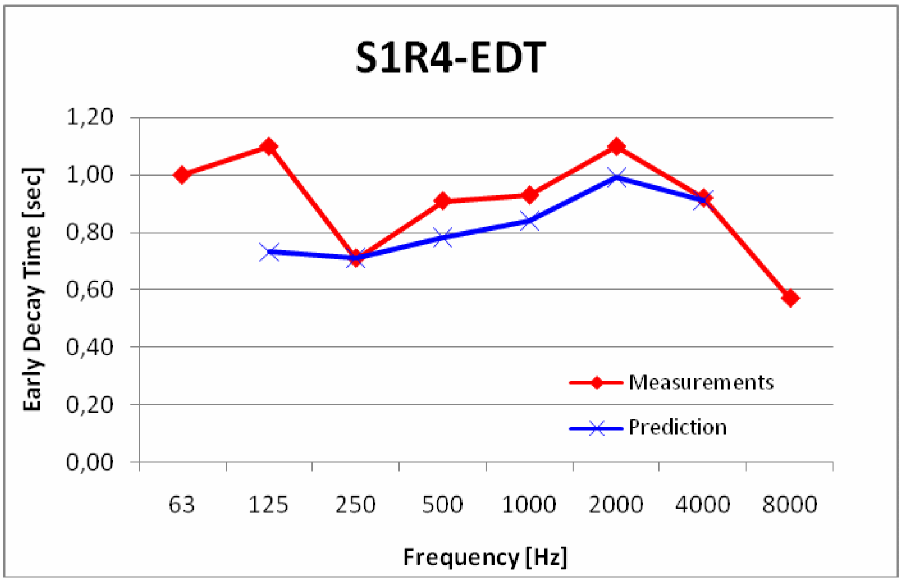

Figure 21 *A comparison measured and predicted early decay time for receiver position 4.*

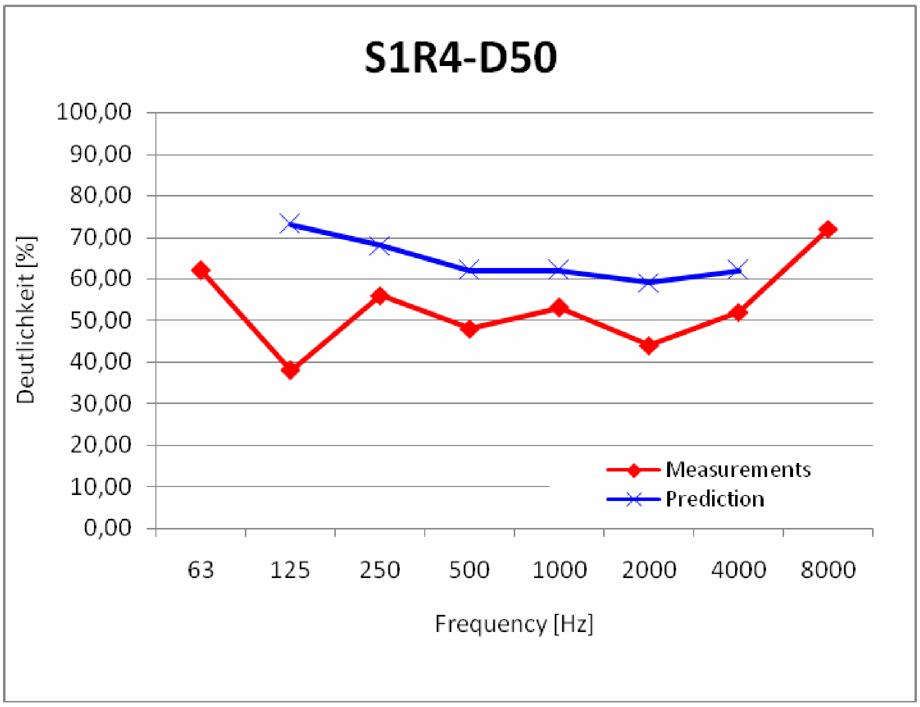

Figure 22 *A comparison measured and predicted Deutlichkeit for receiver position 4*

1.5. Discussion

When the CATT-model was programmed a certain simplification was made for the side walls. This could affect the predicted results, especially around the mid-frequencies where the efficiency of the diffuser is highest. At the time of writing these walls have not yet been precisely modeled for comparison with the simplified model.

The diffusive pattern on the side walls is not a true MLS-diffuser. The final pattern is in two levels which should result in broader frequency range of the diffuser.

2. CONCLUSIONS

A reasonably good agreement was found between the measured and predicted results. The agreement, though, varied though the audience area.

When programming computer models acousticians must be careful when deciding what they should leave out and what they should model precisely. After design it is important to carry out measurements for comparison with predicted results in order to increase ones programming skills and to gain a deeper knowledge about the modeling program in use.

3. REFERENCES

[1] Cremer, L and Müller, H.A., *Principles and Applications of Room Acoustics – Volume 1*, *Applied Science Publishers*, 1982.

[2] Byggforsk., *Innvendig kledning – Lydspredende Flater (dissurorer),* Byggdetaljer 543.424, sending 2, Norges byggforskningsinstitutt 1999.