

Danish Acoustical Society Round Robin on room acoustic computer modelling

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Summary

When modeling the same class room with high absorption in the ceiling and relatively hard surfaces on the walls the acoustics and especially the reverberation time will be dominated by the horizontal reflections far from diffuse field conditions. If extremely absorbing or extremely reflecting surfaces are added in the Odeon model the resulting simulations will be more sensitive to small changes and most likely give much higher reverberation times than what is realistic. This was the most important lesson learned from the current Round Robin initiated by Danish Acoustical Society, where 8 different modelers modeled the same room in Odeon. Some lacks in the check of overlapping and warped surfaces influenced the initial very differing results between the 8 simulations and the set of measurements taken. It is therefore recommended to check the model thoroughly, avoid extremes in absorption coefficients and to look at other parameters than just the reverberation time when simulating the acoustics in dry rooms. STI is a good parameter for acoustics in classrooms or other rooms where speech intelligibility is important.

The assignment

The room acoustical software Odeon has been verified in different round robins. The modeled results of Round Robin II [1] and III [2] are shown on the Odeon homepage www.odeon.dk. In 2007-2008 the Danish Acoustical Societies group of room and building acoustics initiated this round robin. The aim of this round robin was to compare measured room acoustical parameters in a class room with simulated ones when simulations are made by different teams creating their own Odeon models; entering their own data for geometry, absorption, scattering, calculation parameters, source and receiver positions etc.

Eight users of the Odeon room acoustical software participated in the round robin, creating their own model of the same classroom. The participants were given a set of drawings scale 1:50. The floor plan is seen in Figure 1 (the figure is not show in the correct scale). Photos of the class room were provided along with a rough description of the surface materials, making the assignment comparable to a realistic project for an acoustician where most, but not all information is given before the modelling takes place.

This Round Robin stands out from Round Robin II [1] & III [2] in several points:

In this Round Robin Odeon is the only modelling tools used in Round Robin II [1] & III [2], several software were competing.

In this Round Robin only one set of measurements are used for comparisons. In Round Robin II [1] & III [2] several sets of measurements were taken by several different teams with different equipment, so a mean of these measurements could compensate for any problems with measurement tools positions etc.

In this Round Robin modellers create their own room geometry, absorption and scattering of surfaces, source and receiver positions, based on drawings of the room, photos and a description in words. All of the above were exactly specified in the final parts of Round Robin II [1] & III [2].

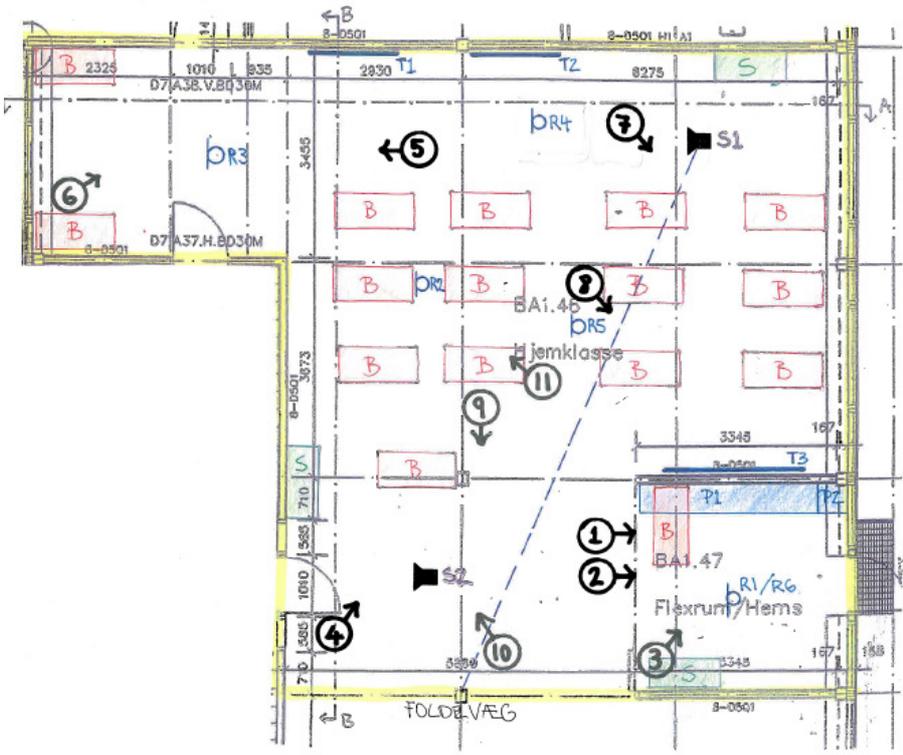


Figure 1. Floor plan of classroom showing source and receiver positions (S1-S2, R1-R6).

Initial Result of the assignment

Users conducted their simulations in different versions of Odeon. However from version 8.0 where the reflection based scattering and frequency dependent scattering was introduced and up there is no major changes in the calculation principles, therefore it is only participant P2 who modeled in Version 4.2, that uses calculation algorithms that differs significantly.

The first set of results presented very differing results both between the different modelers but also between different models and the set of measurements taken. These results are presented in the following.

Reverberation times; EDT and T_{30} at 1kHz are shown at receiver 1 to 6 for Source 1 and for source 2 in the following 4 figures.

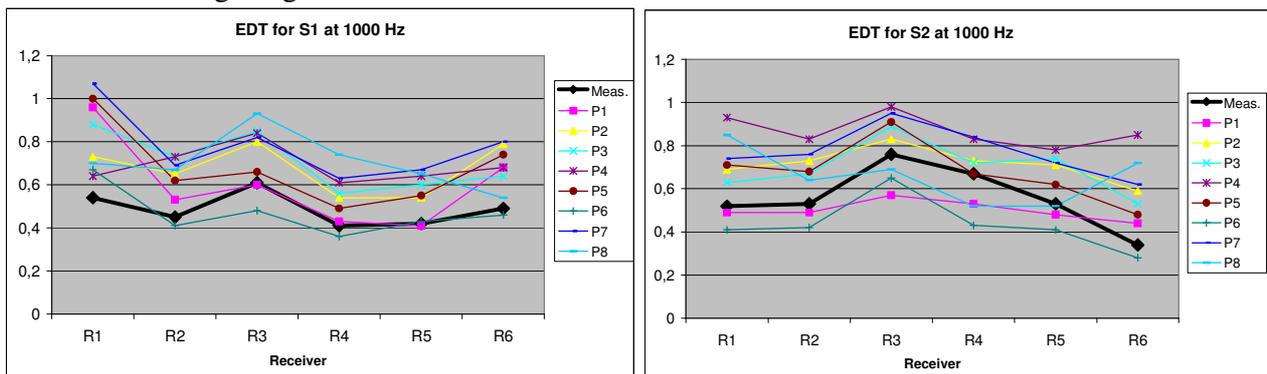


Figure 2. Early Decay Times EDT for source 1 and source 2 at 1kHz.

The EDT curves show a large deviation between the different models and the measurements at 1kHz. According to ISO 3382-1 the Just Noticeable Difference (JND) is 5% for EDT, i.e. 0,03 s for an EDT at 0.6 seconds. So for EDT a spread in the results of 5 JND is common and in point 1 or 6 there are differences of up to 16 JNDs.

The EDT on the other hand shows a repetition of the tendency depending on position and hereby the character of the room. E.g. it is easy to see receiver 3 being the only receiver placed under a reflecting ceiling. So the surfaces near the receiver effects the short reverberation time in both measurements and models. This tendency is also visible in other parameters such as Clarity and STI shown later.

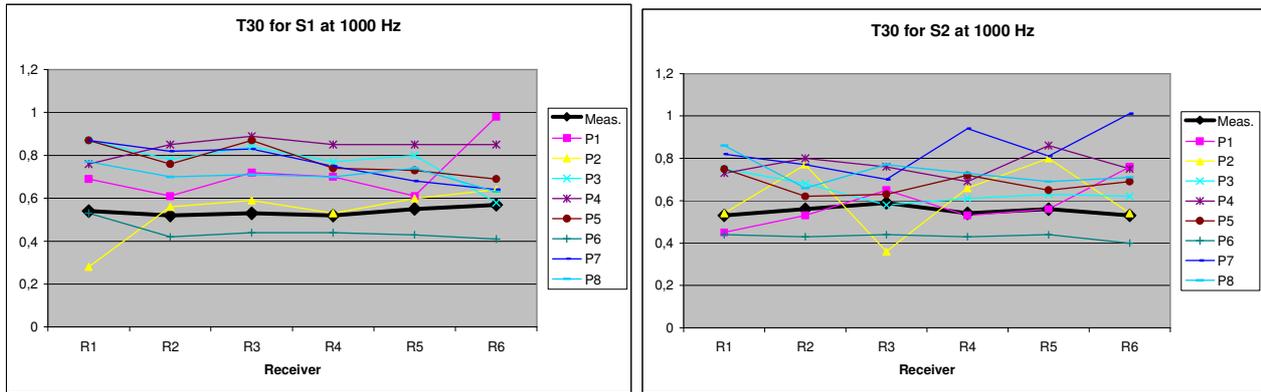


Figure 3. Reverberation times T30 for Source 1 and source 2 at 1KHz.

There are large differences between reverberation times (T_{30}) from different models. A Just Noticeable Difference is again 5% for T_{30} , being 0.03 s in this case. From the above figures it can be seen that in the majority of cases the differences between the measured reverberation time and simulated in different models are very noticeable around 5 JNDs. The maximum deviation in position 6 is as much as 17 JNDs. On average the spread in the results is around 8 JNDs.

Comment: a JND of 5% is probably suggested in ISO 3382-1 with concert hall design in mind where T_{30} is typically around 2 seconds and thus JND is 0,1 seconds; we doubt that a difference of 0.03 seconds is audible.

Sound pressure level SPL is shown at receiver 1 to 6 for Source 1 and for source 2 in the following 2 figures. As the SPL here is relative to the direct sound in the distance 10 m in a free field, it is the same as the Strength, G, in ISO 3382-1.

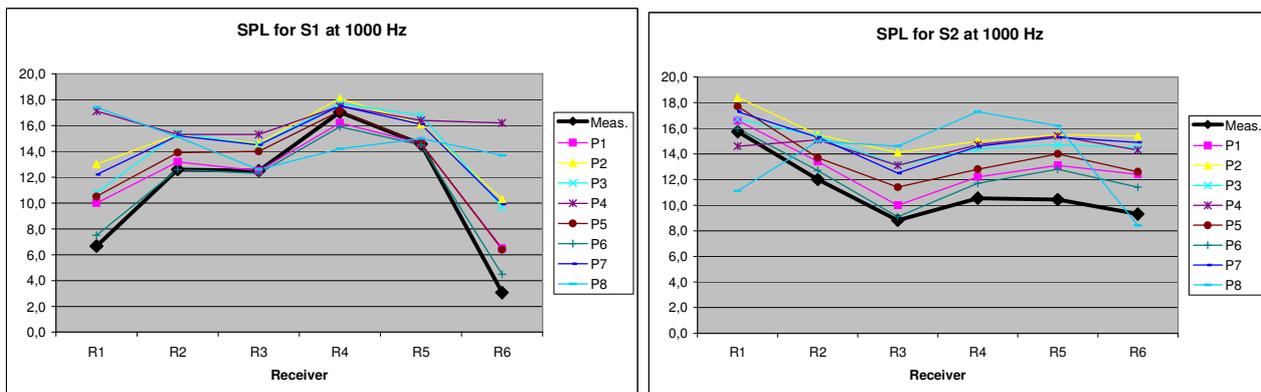


Figure 4. SPL at 1000Hz.

JND for SPL is 1 dB. Sound pressure at 1 kHz varies mostly around 4 dB but up to 7 dB in different points between modeled and measured.

Clarity; C_{80} at 1kHz are shown at receiver 1 to 6 for Source 1 and for source 2 in the following 2 figures.

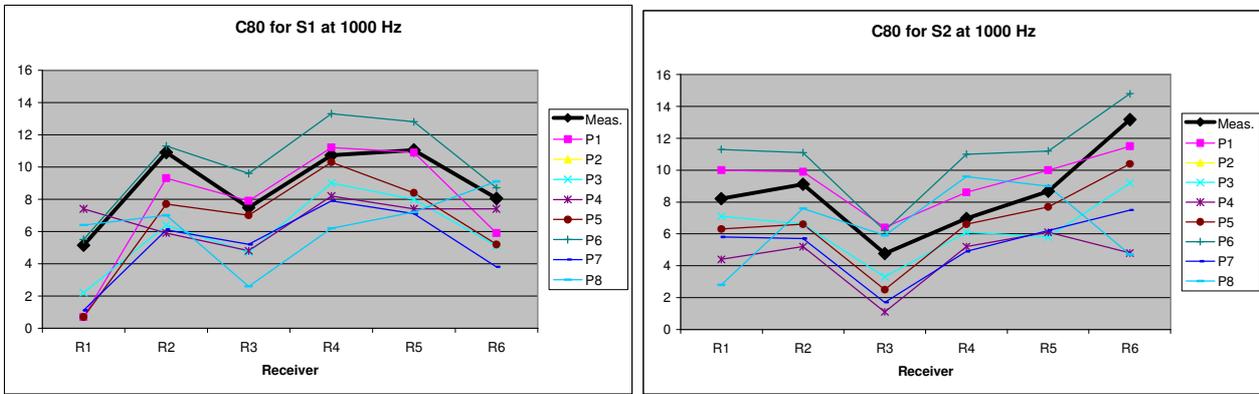


Figure 5. C_{80} at 1000 Hz

C_{80} have a JND of 1 dB, C_{80} at 1 kHz varies mostly around 3 dB in different points and up to 8 dB in two cases at receiver 6. So C_{80} and SPL varies in the same range of JNDs a little less than reverberation times but still a lot.

Speech transmission index; STI are shown at receiver 1 to 6 for Source 1 and for source 2 in the following 2 figures.

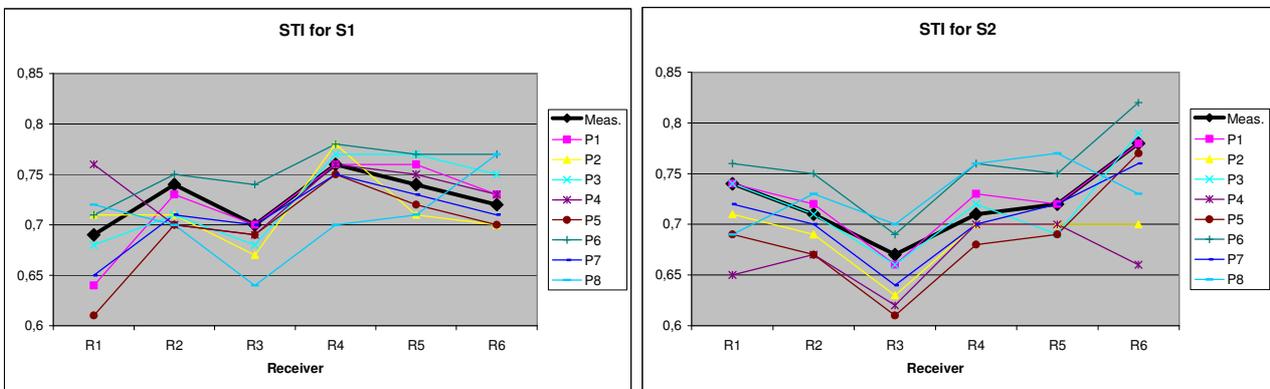


Figure 6. STI (note y-axis is zoomed)

JND for STI (Speech Transmission Index) is 0.05. STI has much smaller deviation than was the case for reverberation time. STI varies around 2 JNDs, where the reverberation times vary around 8 JNDs.

The Reverberation time, SPL and C_{80} are strongly dependent on each other, so in many cases this report will concentrate on the reverberation time, being the normally used and well known room acoustic parameter. Also the Reverberation time is the most sensitive parameter as can be seen above. The STI is interesting, because it is not as strongly dependent on the reverberation time alone, and STI is less sensitive to small variations in position and absorption data, and this will be commented in the report as well.

The DL_2 parameter was simulated in the models as well, but there has not been made any measurements of this parameter; therefore and because the room is very small for using the DL_2 parameter (there is only a small difference in SPL between the receiver positions), this is not commented further in the report.

It has been analyzed which input to Odeon is making the different models differ this much from each other and from measurements. Also the accuracy of the measurements is discussed.

Measurements

According to the recommendations in the ISO 3382-2 standard the distance of sources and receivers from the walls should be at least $\frac{1}{4}$ of a wavelength, or approximately 1 m for 125 Hz. Receiver R4 is approximately 0.85 m from the wall and R6 is approximately 0.6 m from the ceiling.

Comparisons between 3 sets of measurements showed differing results due to differing positions differing measuring devices with different signal to noise ration, etc. To obtain more reliable measurement results, an average of a large number of measurements should be used (the orientation and position of source should probably also be shifted slightly).

So the fact that the comparisons are made with only 1 set of measurements should be taken into account. Further because of a pour S/N at 63 Hz these data are not presented. S/N for the 125 Hz band may not be too reliable either.

Average difference (12 source receiver pairs) between two sets of parallel measurements normalized to JND when the microphones were moved by just 15 cm in the second set of measurements caused large differences.

Parameter	Average deviation in JND (12 source receiver pairs)	1 JND
EDT	2.5	5%
T30	1.2	5%
C80	1.2	1dB
D50	1.2	0.05

EDT has an average deviation of 2.5 JND's between the two measurements – for a selected receiver the difference was as high as 5.5 JND's. STI is not included in the table, but in fact STI was the exception being closer; less than 1 JND from the second shifted measurement.

Placement of Source and Receiver

For some of the source receiver pairs there is no direct sight between source and receiver: S1-R1, S1-R6, and S2-R3. For receiver 6 placed on the loft, the models did not include the railing towards the room which was not only closed by vertical bars but also by horizontal plastic strips making the sounds paths even more complicated, see Fig. 7.



Figure 7. Photo showing the railing shading receiver R6 from the rest of the room.

If the source and receiver are not placed at the same spots when measured and simulated, there can be a significant difference in results. (Differences will appear both for measurements and simulations in particular in receiver points with a small distance to the source). In this round robin users had to extract the positions from the drawing seen in Figure 1. In figure 8 is seen one of the models with placement of source and receiver positions.

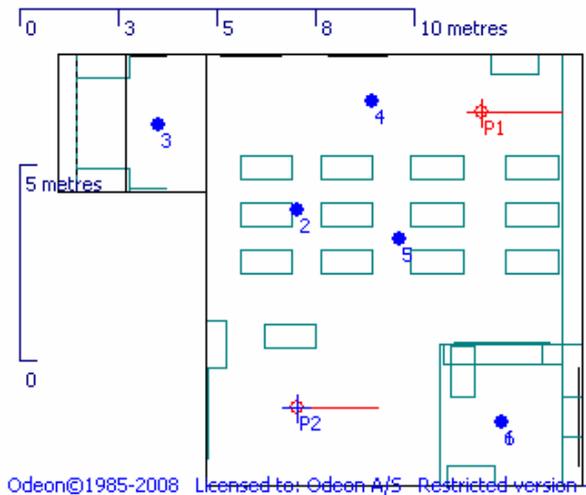


Figure 8. Placement of sources and receivers in one of the models.

There were some differences in the placement of sources and receivers in the modelled rooms. Usually the difference was within 0 to 10 cm; but in some cases differences up to 30 cm were observed (Receiver 3: P1 versus P8).

To see what influence different receiver positions may have on simulations, a small grid of 0.25 x 0.25 metres with a resolution of 5 centimetres has been calculated around one receiver point (R4). The results of this calculation are shown in Fig. 9 and 10 for source 1 and 2.

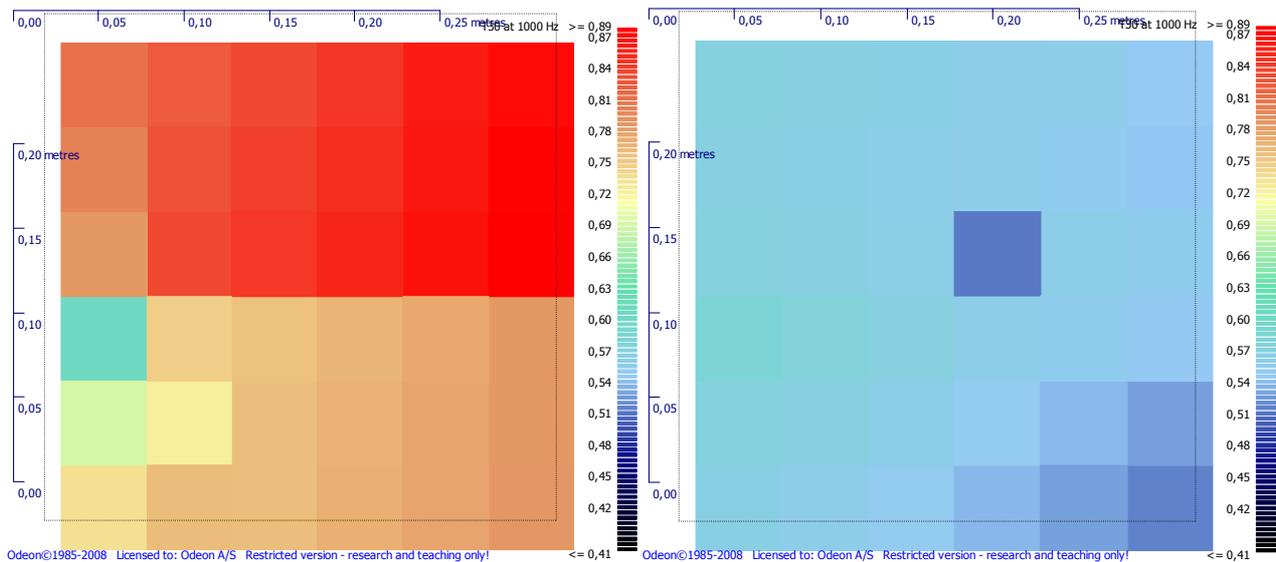
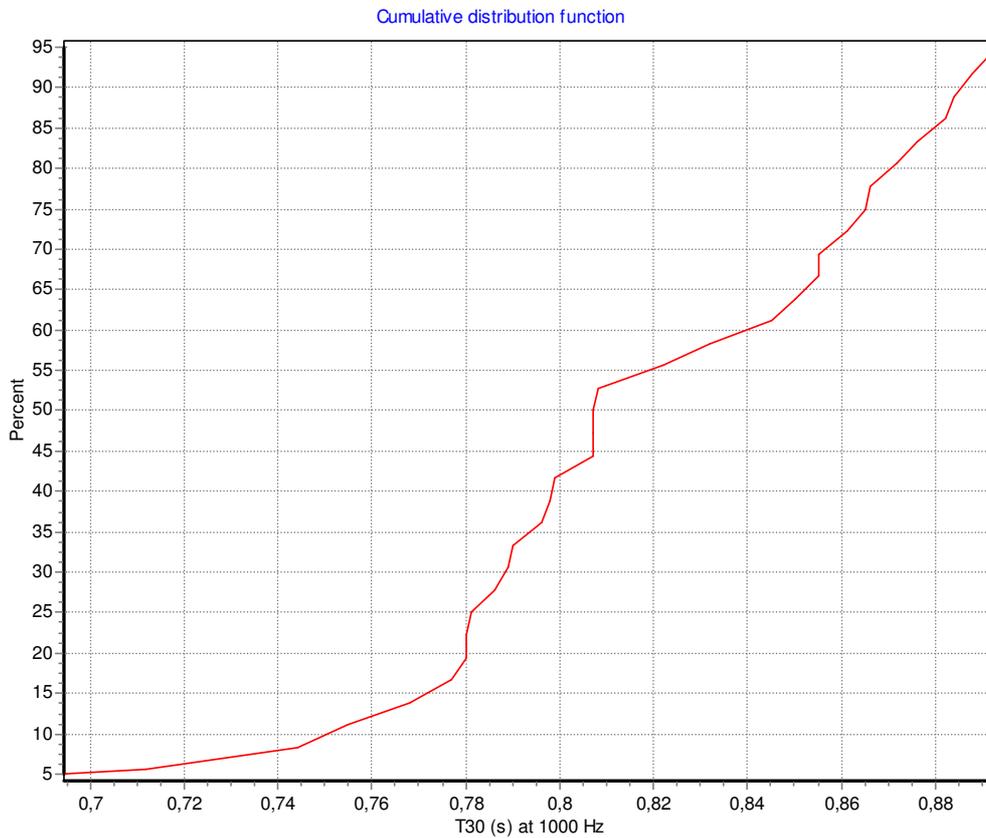
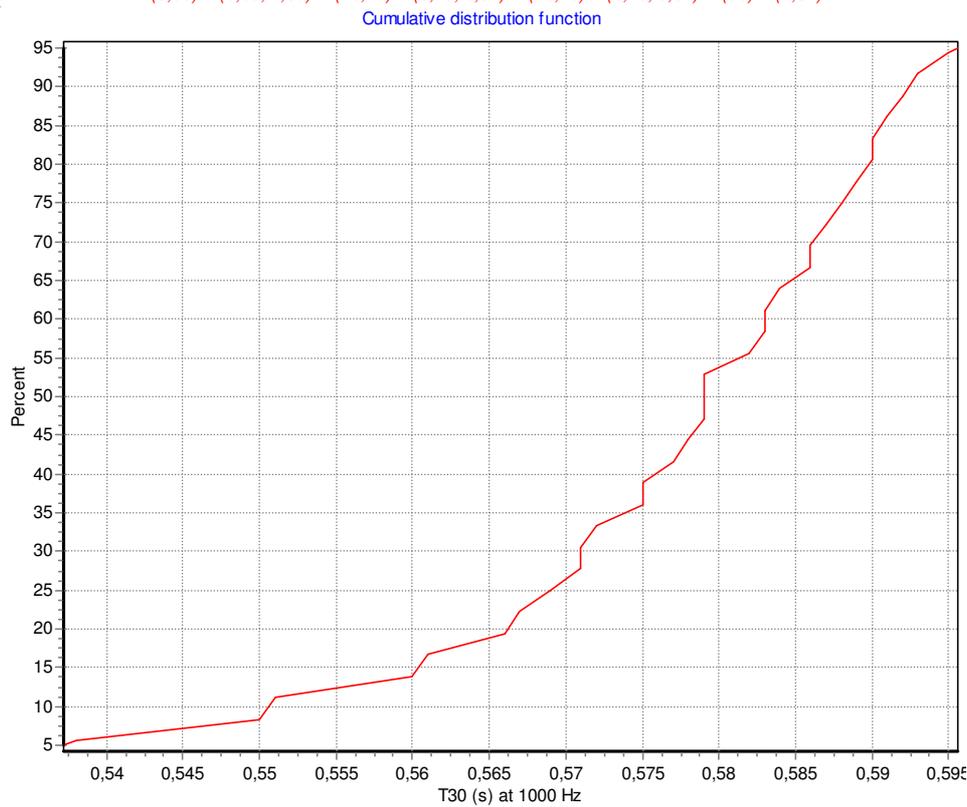


Figure 9. 30 cm x 30 cm grid showing the variance in T30 for every 5 cm at around receiver R4. Source 1 in top, Source 2 bottom.



$X(95)-X(5) = 0,20$ $X(90)-X(10) = 0,14$ $X(75)-X(25) = 0,08$
 $X(5,95) = (0,69, 0,89)$ $X(10,90) = (0,75, 0,89)$ $X(25,75) = (0,78, 0,87)$ $X(50) = (0,81)$



$X(95)-X(5) = 0,06$ $X(90)-X(10) = 0,04$ $X(75)-X(25) = 0,02$
 $X(5,95) = (0,54, 0,60)$ $X(10,90) = (0,55, 0,59)$ $X(25,75) = (0,57, 0,59)$ $X(50) = (0,58)$

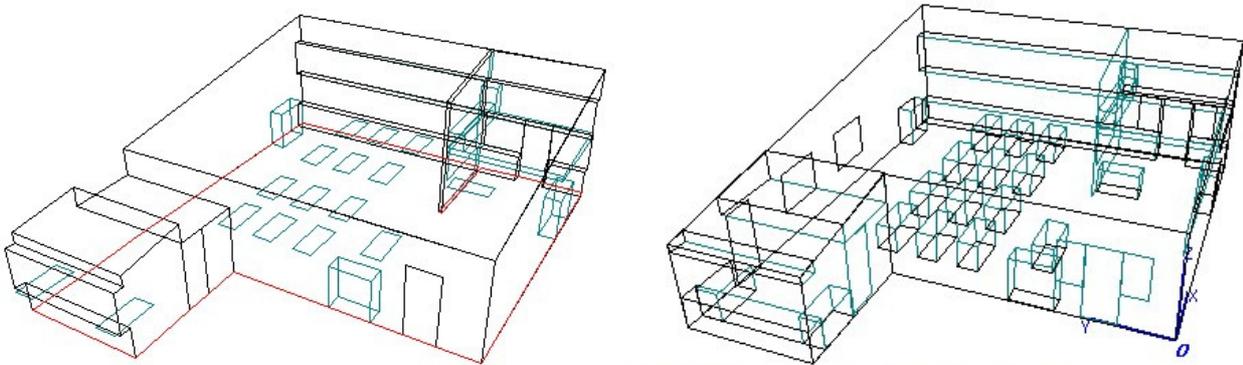
Figure 10. Statistical results of grid calculation as in Fig. 9. Source 1 top, Source bottom.

It is seen above that for every 5 cm change in position of a receiver, T_{30} can change more than a 1 JND (5%). When the source is close to receiver as in the top figures, the variation within the 90% fractile in the selected area is 4 JNDs and when the source is far from receiver 2 JNDs.

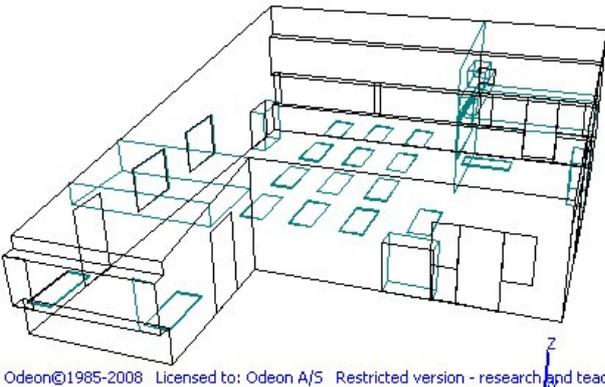
For measurements the difference in the parameters due to difference in position will be addressed in the following chapter.

Room Modelling.

There should be room for different kinds of modeling of geometry. And this has also been the case in this round robin where e.g. tables have been modeled both as planes, plates or boxes. Also walls were modeled with more or less detail e.g doors, windows etc. Some examples below are shown below.



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Figure 11. P1, P6 and P5 shows different wais of modelling.

Overlapping surfaces

The different ways of modelling tables are not a problem, but we recommend that when modelling a box with a surface overlapping another surface, the not used surface should be assigned *Material 0*. When tables are modelled as boxes the boxes should only be modelled with the Top. Odeon normally have no problem with a certain amount of overlap or gaps in a model, however for good modelling practise try to avoid this. In some cases it can be a problem if two overlapping surfaces have different absorption, then it is not clear which absorption should be used by Odeon. There were two examples of this in the received models. One is shown in figure 18. *3D Geometry Debugger* or *3DOpenGL* tools can help detecting or viewing this type of error.

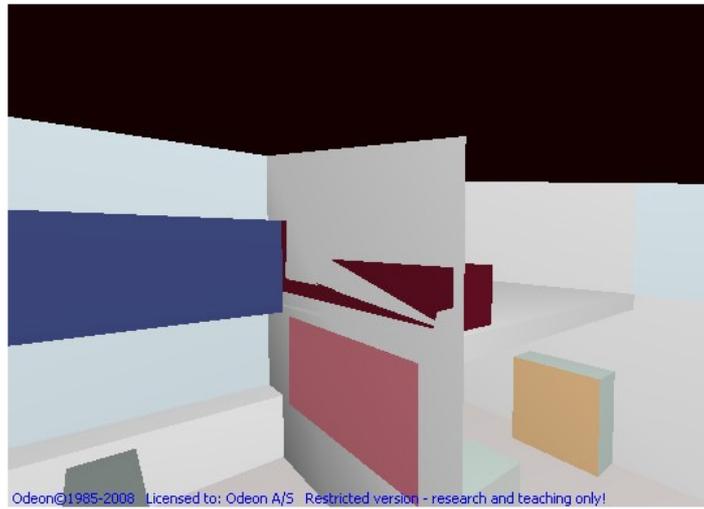


Figure 12. Overlapping surfaces can be a problem. In this case Odeon may use the high absorption coefficient of the furniture behind the wall, were it was supposed to use the hard wall material.

Misplaced surfaces

In yet another room the pin-board (pink rectangle in figure 18) was misplaced by 10 cm thus hidden inside a wall. *3DOpenGL* tools can help detecting or viewing this type of error.

Warped surfaces

Another very severe problem found in several of the models was a warped ceiling surface. This error leads to a loss of some of the rays, giving raise to some unexpected absorption. The *3D Geometry Debugger* tool can help detecting this type of error.

Three of the geometries had ceilings which were warped. For one of the geometries this led to a loss of 11 % of the rays; after fixing that by changing the Z coordinate by 2.5 cm for two of the corner points the predictions improved considerably (two overlapping surfaces were also fixed). See below sample graphs for EDT and C_{80} before and after geometry was fixed.

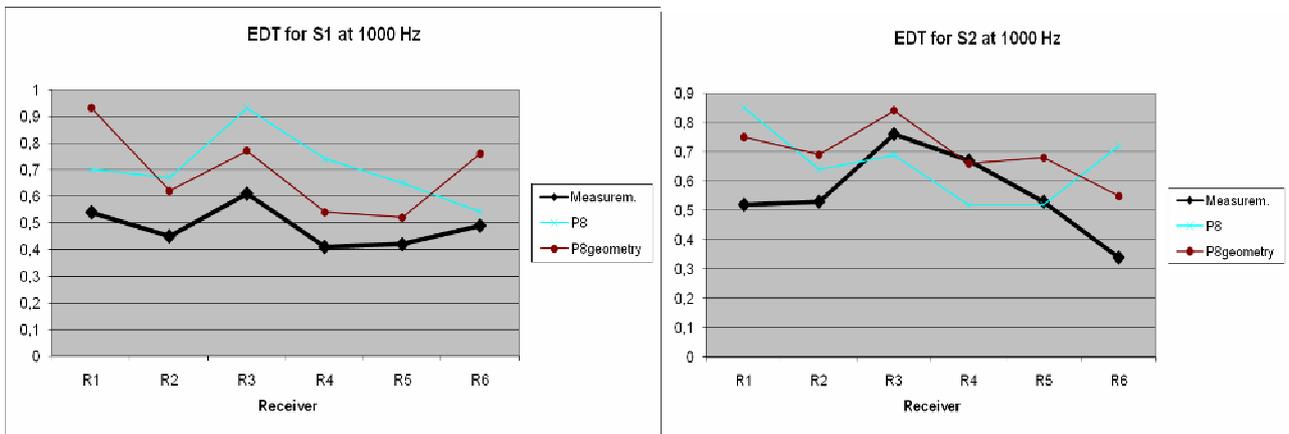


Figure 13. EDT in P8 before and after correcting warped ceiling surface

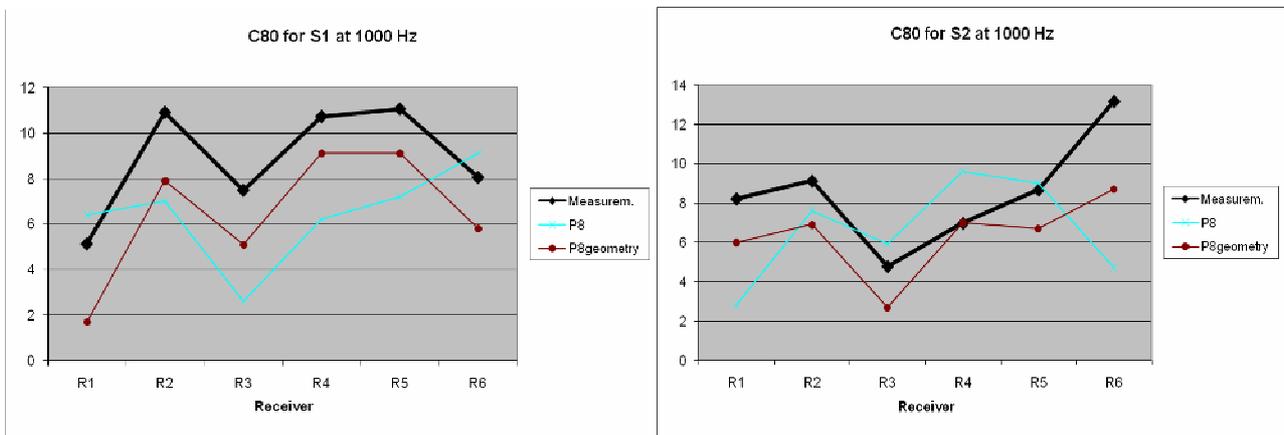


Figure 14. C_{80} in P8 before and after correcting warped ceiling surface

Absorption

Inspecting the different absorption coefficients used in the participating room models it is clear that the difference in predicted reverberation times may, at least partly, be explained by differences in absorption data. In the low frequency range this difference could be caused by the users not knowing the thickness of the material and the cavity behind it from the project description. On the other hand, all the received models had exactly the same floor material because the floor was described as wooden floor directly on concrete, and there is given a standard absorption-coefficient for this in the Odeon material list.

The wood wool ceiling contributes most to the total absorption area. In Sabine calculations where perfect diffuse field conditions are assumed – there will be a direct effect of the absorption coefficients of the ceiling in the predicted reverberation time. *For none diffuse sound fields, the effect of increased ceiling absorption may be counter intuitive. In principle increasing the absorption of the ceiling close to 100 % absorption can in fact lead to longer reverberation time because this leads to a 2-dimensional sound field which becomes dominated by the hard wall material.*

The absorption coefficients used for the ceiling by different participants ranged from 0,3 – 0,7 at low frequency and 0,5 – 0,7 at high frequency – a factor 1.4 – 2.3 depending on frequency, see Fig. 15.

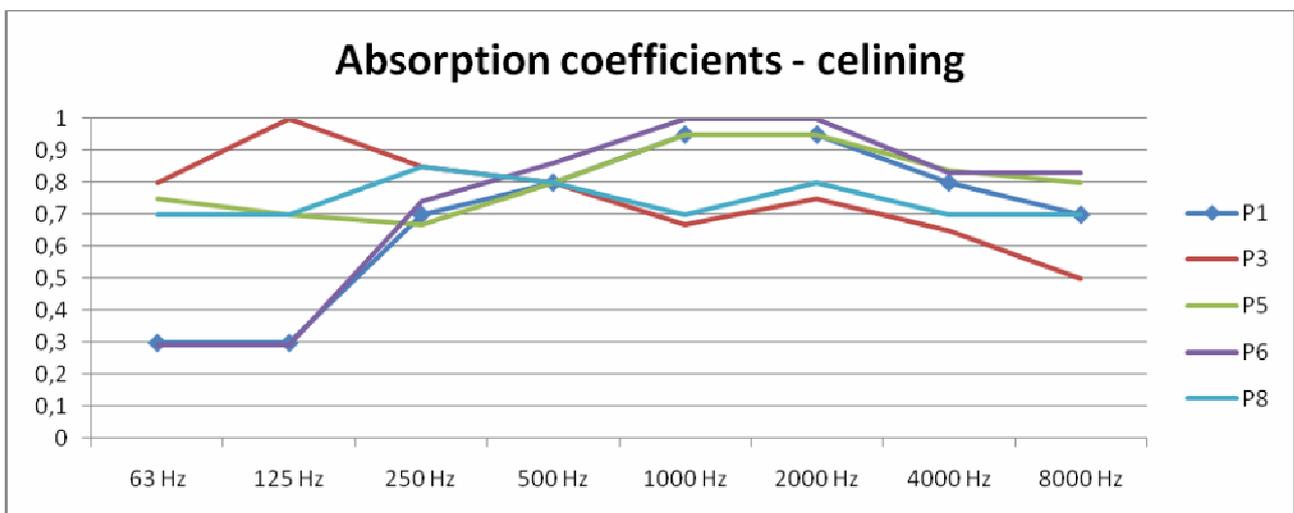


Figure 15. Absorption coefficients used for the ceiling in 5 of the participating models.

The absorption coefficients used for walls by different participants ranged from 0,02 – 0,28 at low frequency and 0,02 – 0,10 at high frequency – a factor 5 – 14 depending on frequency, see Fig. 16.

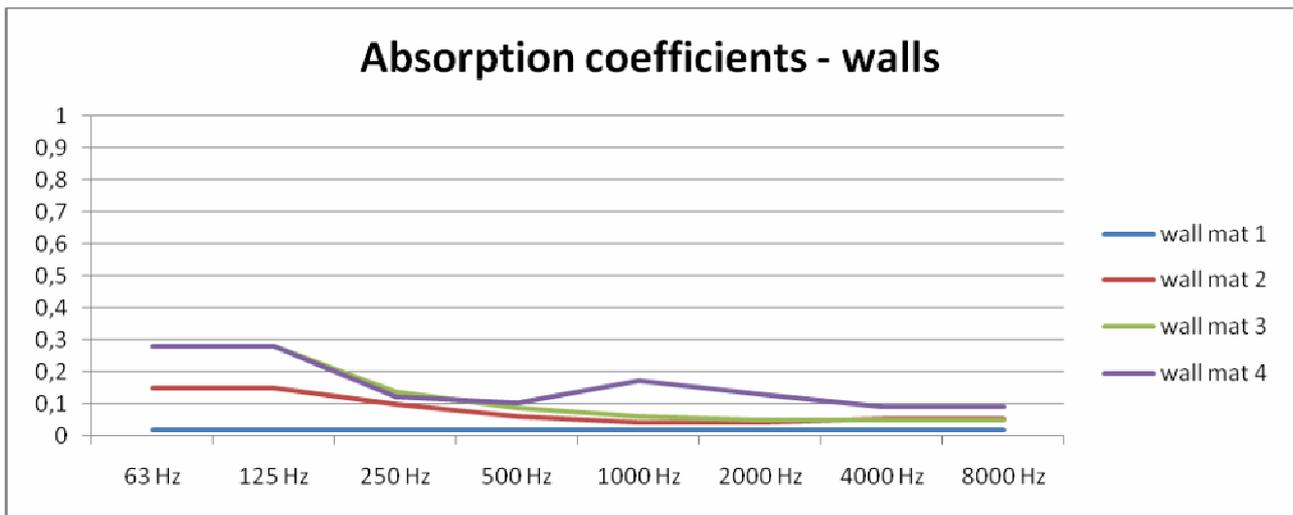


Figure 16. Some different absorption coefficients used for main parts of wall by different participants

If absorption coefficients of the ceiling are very high, then there may not exist any vertical reflections in the late part of the decay, i.e. the late reflections are mainly defined by the reflections from the walls. Therefore when ceiling absorption is close to 100%, changing the absorption of the walls can have a very significant effect on T_{30} and to some extent also on EDT, whereas early energy parameters such as C_{80} and D_{50} are not that sensitive.

Odeon will show large difference in predicted T_{30} if the coefficients in the horizontal plane are altered whereas the Sabine formula by nature will hide the effect of a non-diffuse sound field. The Sabine formula will have a tendency to under estimate reverberation time in non-diffuse sound fields where one- or two dimensional modes are dominant. (In other cases the Sabine formula is known to overestimate the reverberation time, though). Odeon does take into account that reverberation in rooms such as this class room will be dominated by wall reflections – this does in principle allow better predictions than Sabine offers, however relative small changes to the total absorption area may have pronounced effects on reverberation time – in simulations as well as in the real world. Indeed changes of a factor 5 or more for the wall material absorption as in this round robin has a pronounced effect.

Although reverberation time is often used for characterization of class rooms (parallel walls and absorbing ceiling), the question is if it is good at describing the acoustic quality of such rooms; there can be large differences in T_{30} and EDT with some variations in the absorption data, while STI virtually stay unchanged.

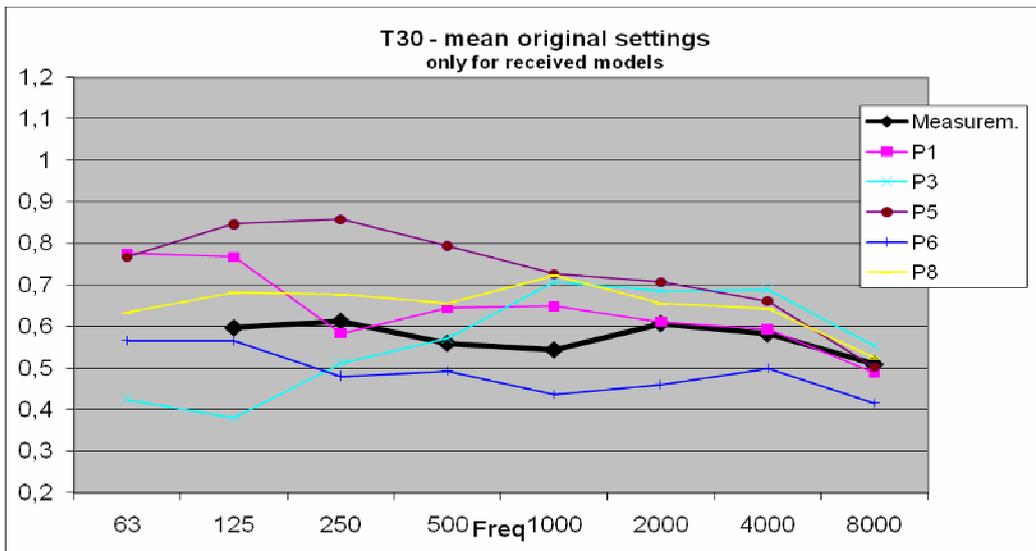


Figure 17. Mean values of T_{30} from 12 source receiver pairs in the rooms as received from participants.

Ceiling absorption is a dominant absorption area. Thus a question is whether results from different participants converge if we use same material for the ceiling. In case we chose to use the ceiling material from P1 (high absorption coefficient at mid frequencies) the results are shown in Fig. 24:

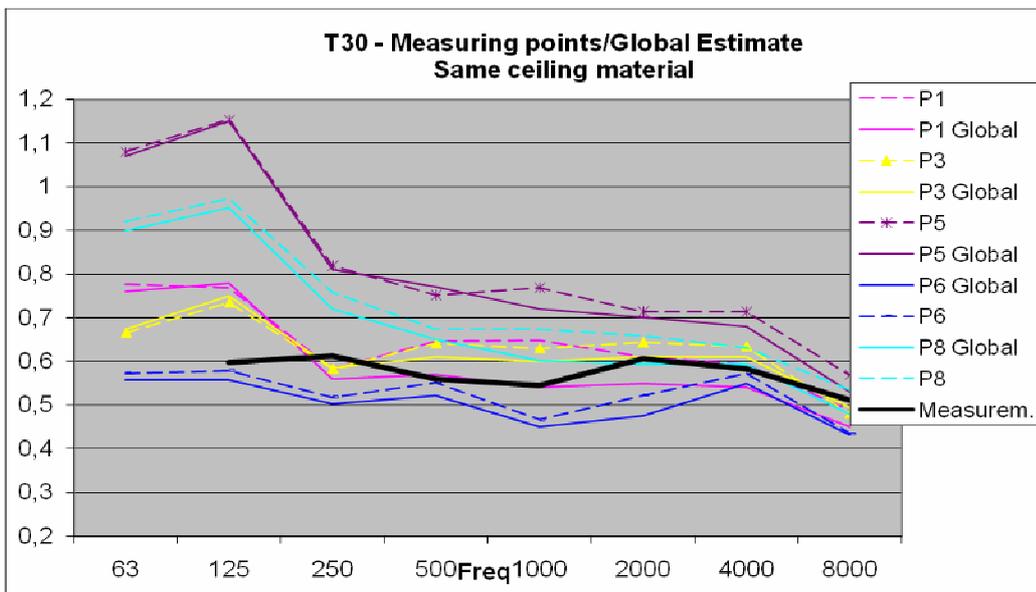


Figure 18. Calculations with same high absorbing coefficients on the ceiling

Although the reverberation curves now have the same tendencies over frequencies *the spread has become bigger*, when using the same absorption coefficient in the ceiling. The problem is that the room is dominated by horizontal reflections and therefore the wall materials (absorption and scattering) become important.

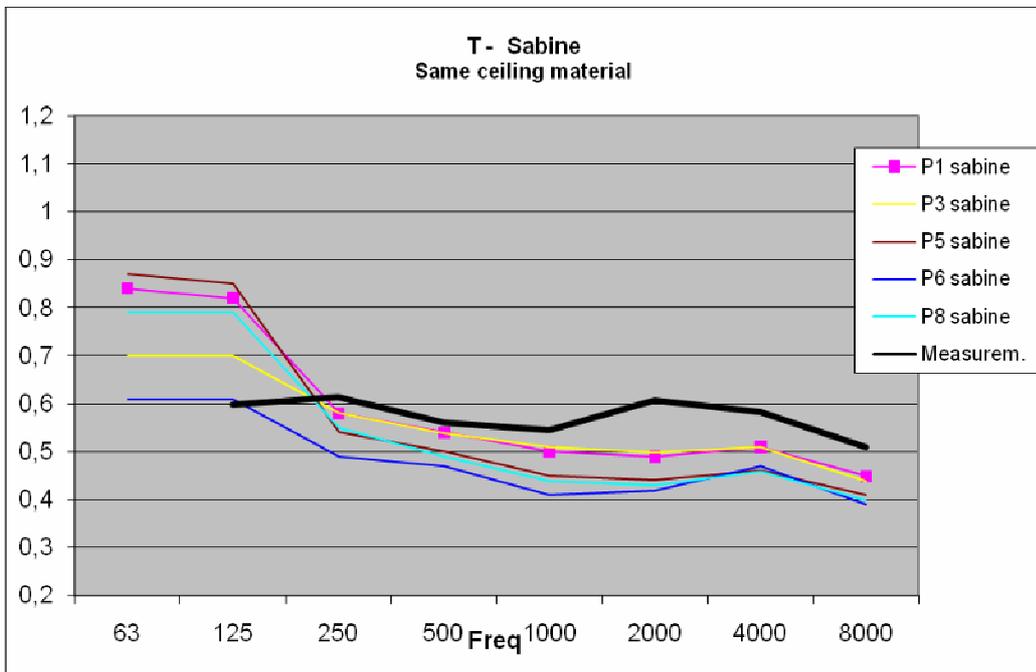


Figure 19. Sabine calculation with all models having same ceiling material.

If we calculate the same reverberation time using the Sabine formula (Fig. 25), results do not show as big a spread as with Odeon.

However, all Sabine calculations are under estimated. This is because diffuse field is assumed – the Sabine formula does not take into account that there will be long living reflections between the hard parallel walls (i.e. some flutter).

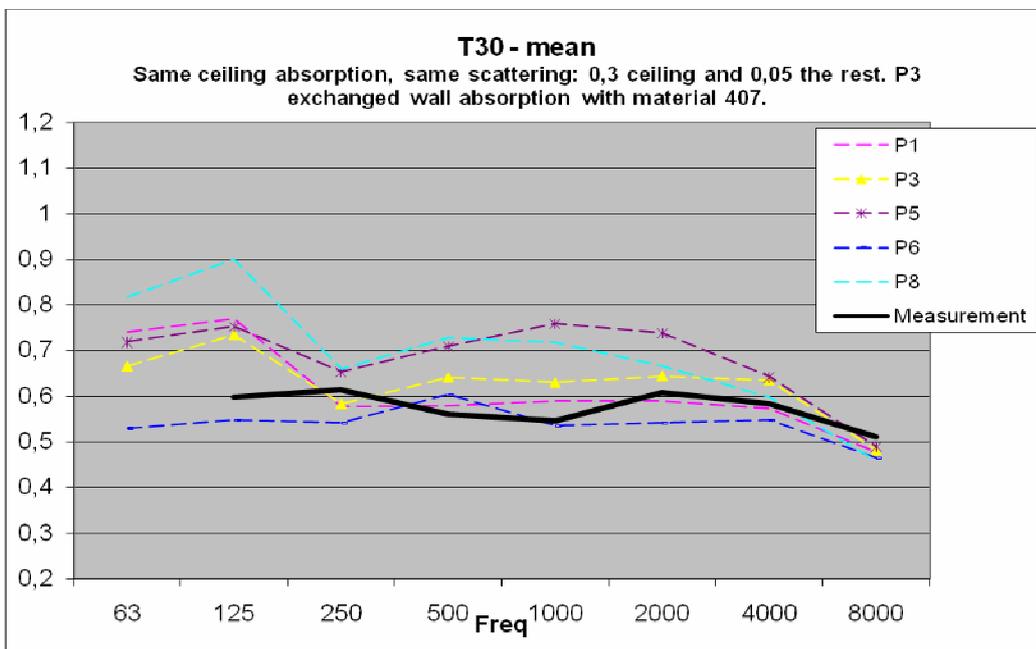


Figure 20. Results of calculations with same ceiling absorption and same scattering coefficients in all models

If fixing all modeling errors in the models, changing scattering to same values in all rooms, using same ceiling materials and changing the wall material of P3 (which was very hard: $\alpha = 0.02$ for all frequency bands), then reverberation between models begins to be in better agreement. Even though

there are still many differences in materials, models are not identical and there are some difference in receiver and source positions.

Scattering coefficient

If objects in the room are modeled to some extent in details a scattering coefficient of 0.05 should be sufficient, if surfaces are larger the scattering should be considered according to the table given in the Odeon manual. As an exception from the table giving in the Odeon manual (based on visual structures added to the modeled surface) an invisible scattering can appear when using very porous surfaces, as E.g. the ceiling with wood wool or a mineral absorber on top of an air gap in these cases a scattering of 0.3 might be a better than the surface visually being judged to a scattering of approximately 0.05.

To look at the scattering influence the simplified modeled case of P1 with a transition order of $TO=1$ and the more complicated geometry P5 with a transition order of $TO=2$ is shown below. for both cases the original scattering coefficient is compared with the default 0.05.

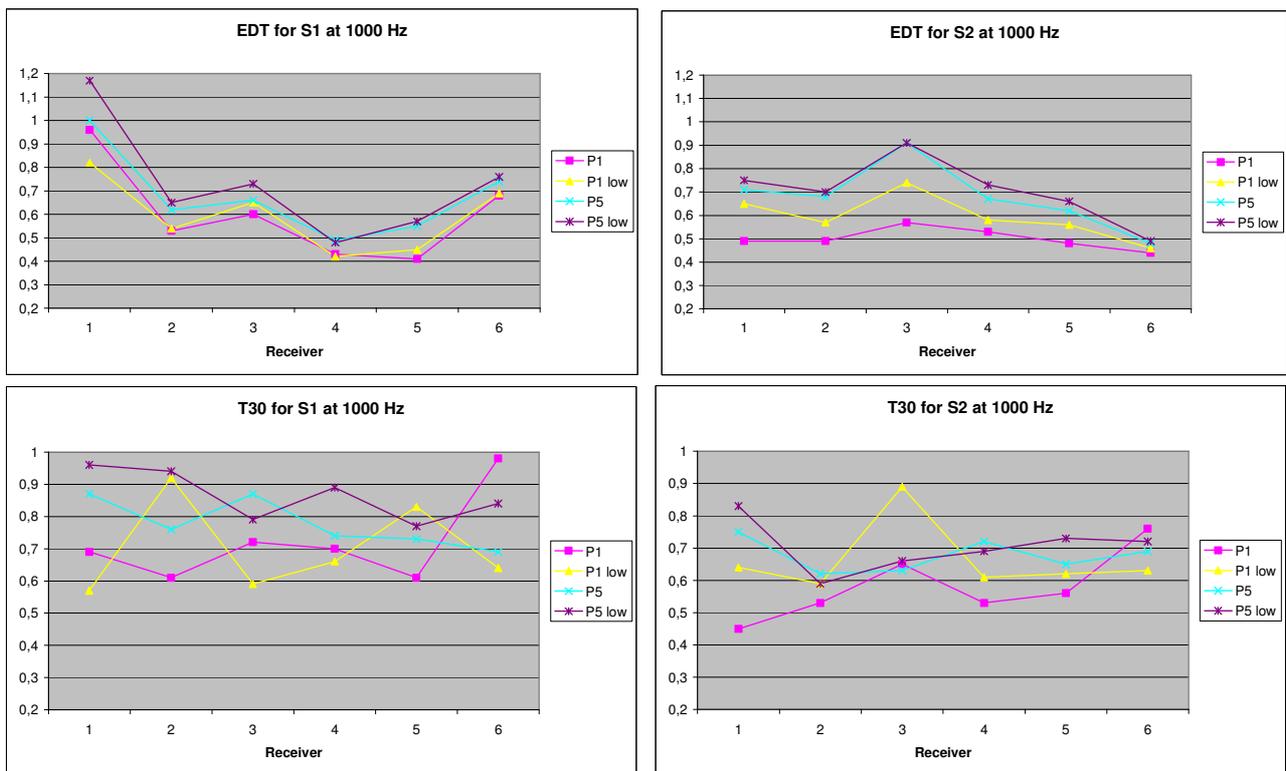


Figure 21. EDT top, T30 bottom. P1: simple room model high scatter, P1 low: simple room model high scatter, P5: complicated model high scatter, P5 low: complicated model low scatter.

The scattering coefficient has an influence on the results. When the model is more complicated the influence of the different scatter setup is not as severe as when fewer surfaces are used in the model.

Transition order

A transition order of 0 means that the model runs only with ray tracing, and the higher the transition order becomes the more specular reflections are taken into account in the simulation. So therefore, if a room has large surfaces visible to source and receiver the Transition Order should be high. On the contrary if the room has many small surfaces compared to the size, a complicated geometry with coupled volumes and/or less visibility between source and receiver the transition order should be low. But every time a modeler makes a new room these factors should be evaluated. It is not enough just to press “Engineering” or “Precision”.

The transition order is normally recommended to be $TO=2$ unless there are many fittings and or a very complicated or coupled geometry. There are a number of fittings in the classrooms and it is

just on the limit of discussion whether the number of fittings compared to the size of the room are so many, that a lower transition order is wanted. In all the received models but P1 the transition order was set to the default value TO=2 in model P1 the transition order was set to 1.

Investigating choice of calculation parameters

Px seemed to be the room having the best agreement between measured and simulated room acoustical parameters. If we assume that this is because it is the model which best mimics the real room, then it may be interesting to use this room for the study of choice of Odeons calculation parameters mainly Transition order and number of rays. Before conducting the study we corrected a warped surface in the model and then adjusted the absorption of the walls in order to best fit the simulated T30's with the measured ones. Then a number of calculations (60) were carried out using various transition order (TO) and number of rays (NR). For each set of TO, NR, an average error normalized to JND's for each parameter and each source receiver pair.

The average error over source, receiver, parameter and frequency is calculated using the following formula:

$$Error = \frac{\sum_{n=1}^{AP} \sum_{n=1}^{Freq} \sum_{n=1}^{Pair} \frac{|AP_{measured} - AP_{simulated}|}{JND}}{N_{AP} \cdot N_{Freq} \cdot N_{Pair}}$$

where

$AP_{Measured}$	= Measured value of parameter
$AP_{Simulated}$	= Simulated value of parameter
JND	= <i>Just Noticeable Difference</i> for parameter
N_{AP}	= Number of parameters
N_{Freq}	= Number of frequency bands, 6 (250-8000 Hz)
N_{Pairs}	= Number of Source-Receiver pairs

Average error in JND's as a function of Transition order (TO) and number of Rays is seen in Fig. 29. The average error is an average over all source receiver pairs and all measured parameters in the frequency range 250-8000 Hz normalized to their corresponding JND.

From the graph can be seen results stabilizes at the lowest error when 1000-2000 rays are used – more rays doesn't improve results (and doesn't lead to worse results either). A transition order of 0 to 3 seems to provide best results – it doesn't seem to be critical which TO is chosen though a transition order higher than 3 cannot be recommended based on this experiment.

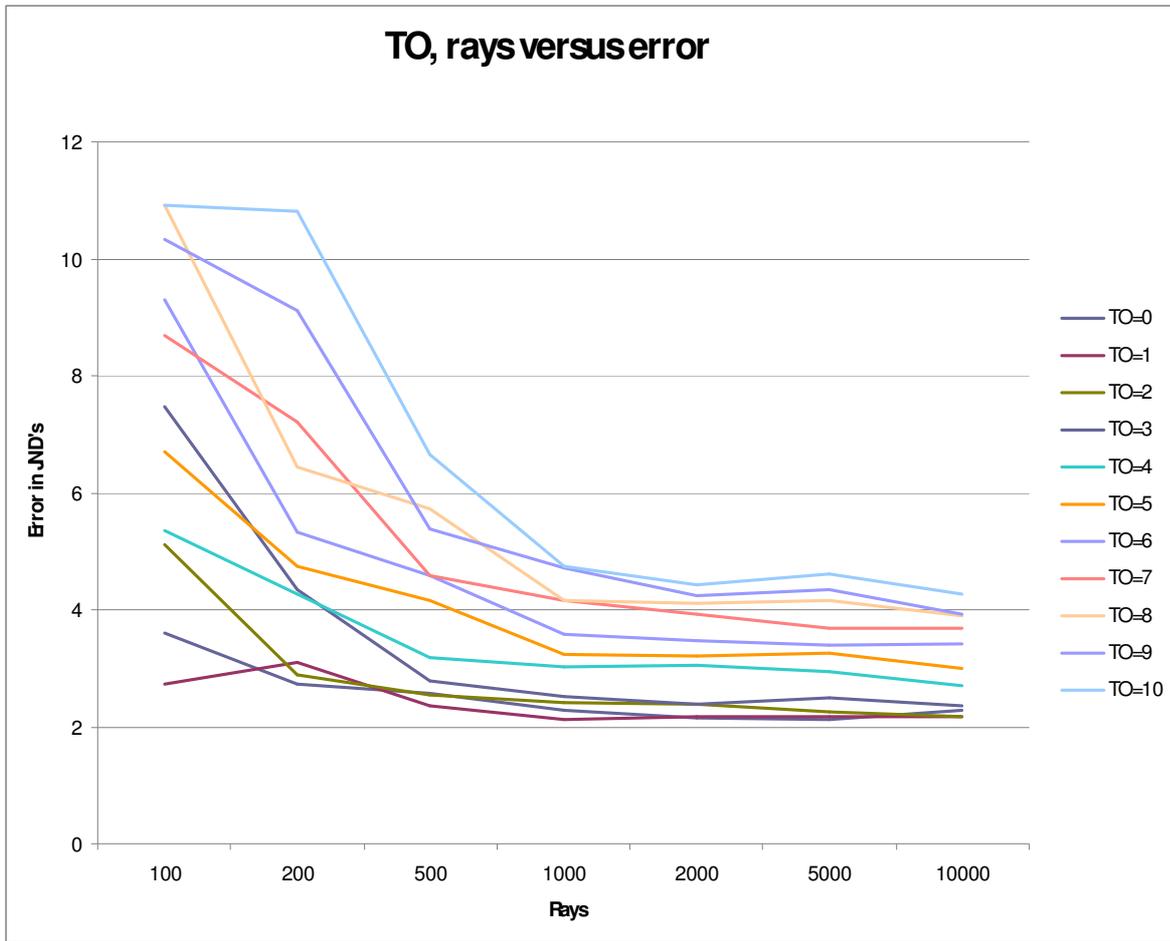


Figure 22. Average error in JND's as a function of Transition order (TO) and number of Rays.

Results with limited extreme absorption coefficients

New calculation have been made with the different room models, but with limiting the extremes values of the absorption coefficients, so the highest absorption coefficient is 0.90 and the lowest is 0.05. The results are shown below in Fig. 23-27.

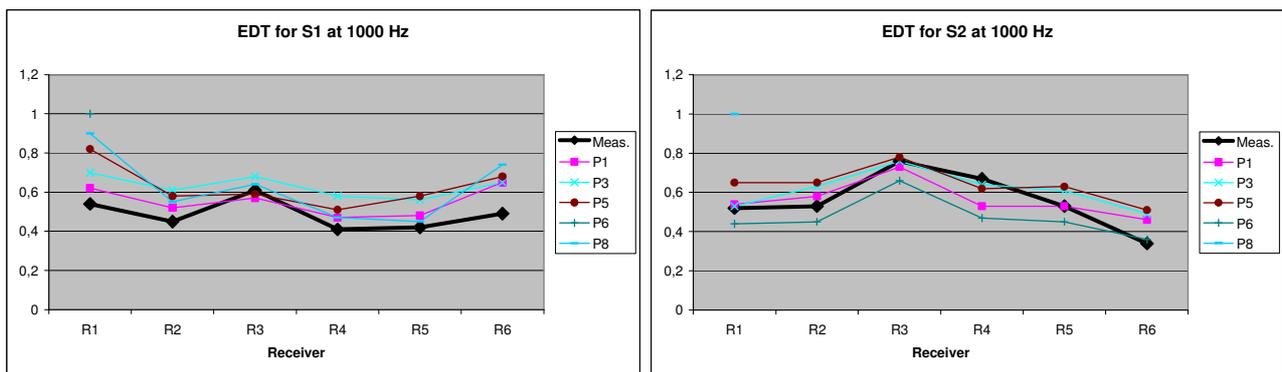


Figure 23. Early Decay Times EDT for source 1 and source 2 at 1kHz with limited extreme absorption.

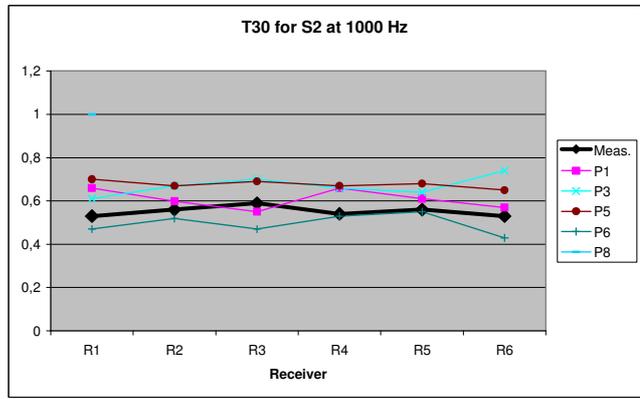
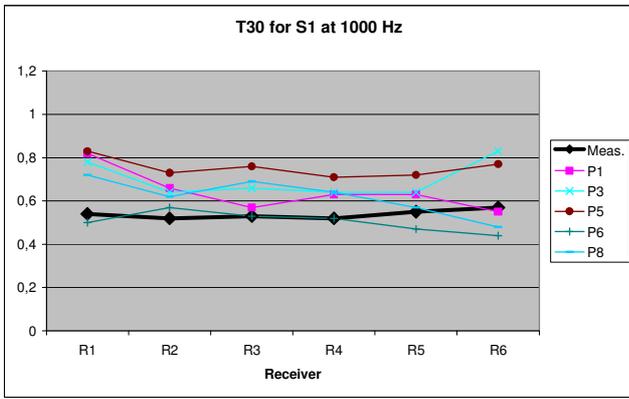


Figure 24. Reverberation time T_{30} for source 1 and source 2 at 1kHz with limited extreme absorption.

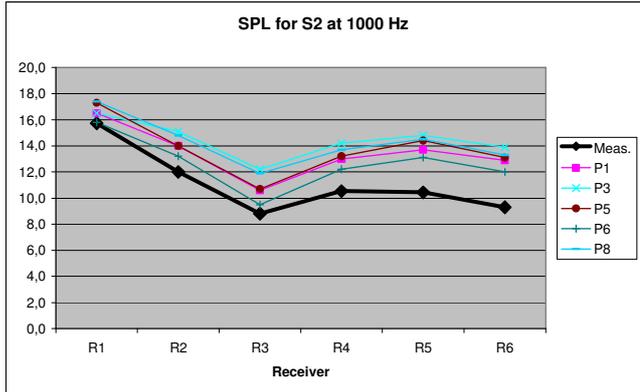
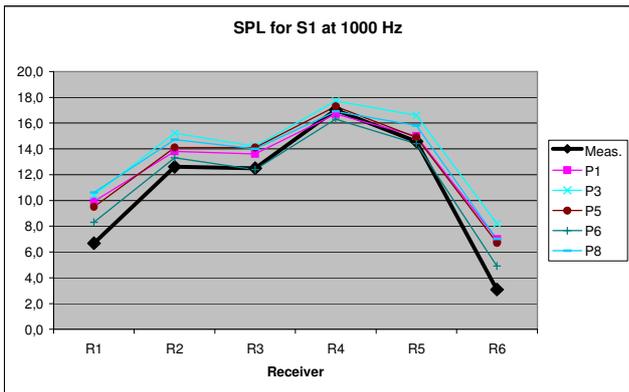


Figure 25. SPL for source 1 and source 2 at 1kHz with limited extreme absorption.

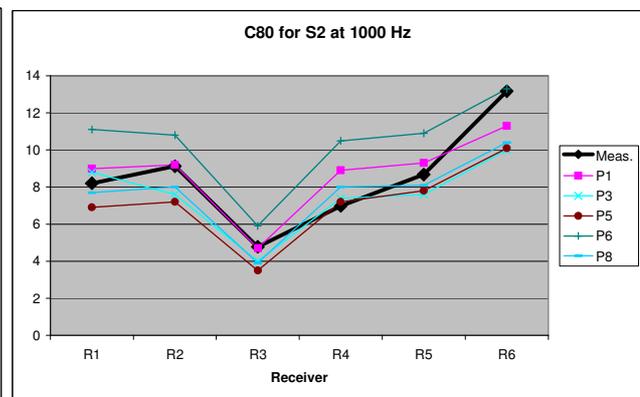
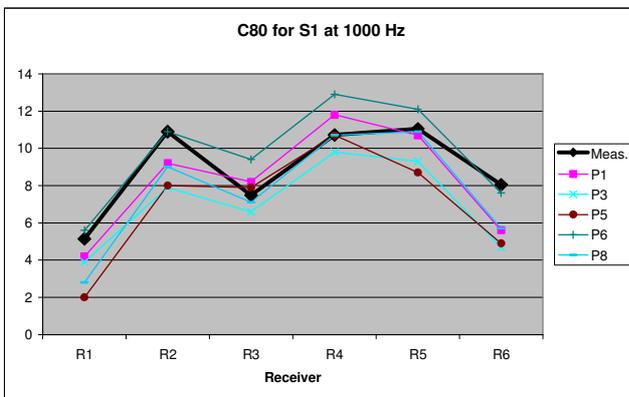


Figure 26. Clarity C_{80} for source 1 and source 2 at 1kHz with limited extreme absorption.

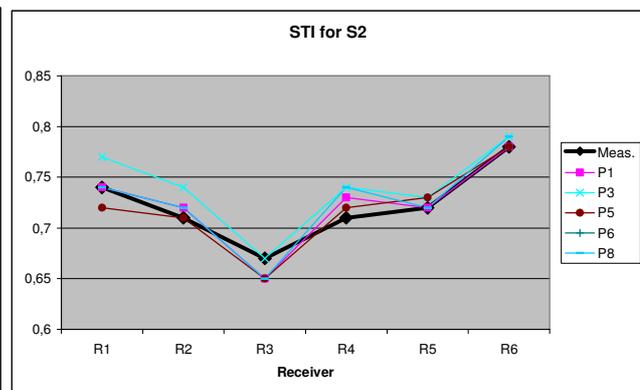
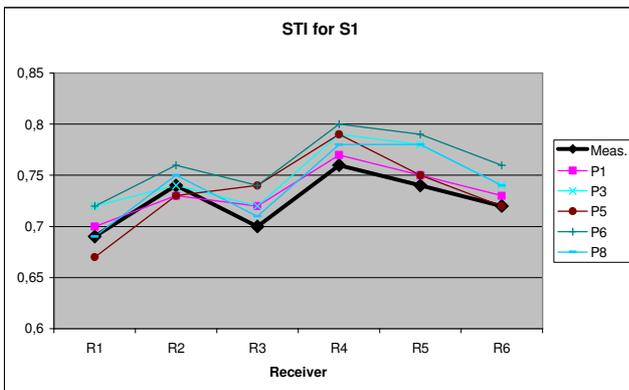


Figure 27. STI for source 1 and source 2 with limited extreme absorption.

Conclusion

There are many possibilities of making errors when doing acoustical modeling in a detailed model, so it is required to keep focus and control with models when using the Odeon program. Preferably other acousticians in the company should check the room model for mistakes.

There were large differences in the absorption coefficients used by the different users. The absorption coefficients used for the ceiling by different participants ranged from 0.30 - .70 at low frequency and 0.50 – 0.70 at high frequency – a factor 1.4 – 2.3 depending on frequency. The absorption coefficients used for walls by different participants ranged from 0.02 – 0.28 at low frequency and 0.02 – 0.10 at high frequency – a factor 5 – 14 depending on frequency.

Late reverberation in the classroom is mainly influenced by reflections between the hard walls therefore these coefficients has to be chosen with care, if reverberation time is the parameter of interest, otherwise results may even be less precise than what's offered by Sabine.

STI is not this sensitive to late reverberation. All participants were able to predict STI with a reasonable accuracy even though models did contain some geometrical errors (positions of sources and receivers and warped or missplaced surfaces).

The transition order should be 0 or 1 if there are several details in the room compared to size of the room. Or if there is no direct sound between source and receiver, otherwise 2 is recommended.

It is important to use lower scattering coefficients than the ones used in earlier versions.

Measurements

Measurements, in particular of the EDT parameter showed large deviations when receiver positions were altered by just 15 cm. An average error of 2.5 JND's for 12 source receiver pairs were found – one source receiver pair had a difference of *more than 5 JND's*. In general for all parameters the error was greater than 1 JND.

Communication and future projects

The exercise has been very good for Odeon A/S to help communicate a best modeling practice. And it is very fortunate that the Danish acoustical society on its own initiative have started this project. It is a step in improving the communication between Odeon A/S and its customers. This project will also in short time result in a best modeling practice or QA – note on the support page on www.odeon.dk.

If another exercise like this should be done to test the Odeon program. More precision in the definition of the assignment might be chosen. It could be considered importing the same dxf file, with the same coordinates for measuring positions and using same absorption data. In this way to exclude some of the unavoidable sources of error and instead focus on the models way of calculating with regards to transmission order, number of ray, desired reflection density and chosen additional scatter coefficients.

On the other hand the testers were also satisfied that this round robin was more minded on the different modelers than on the program it self, so a new similar round robin based on the knowledge from this one, was also requested.

References

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