ODEON, A DESIGN TOOL FOR NOISE CONTROL IN INDOOR ENVIRONMENTS

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SUMMARY

Some rooms are much noisier than other, even with the same noise sources. For the design of low-noise indoor environments it is crucial that both the noise sources and the surrounding room surfaces are taken into account. Using a room acoustic computer model the first step is to model the room surfaces in terms of absorption and scattering properties. Next the sources are modelled, and while some sources may be sufficiently modelled by a simple point source, this is not sufficient for large noise sources. So, lines, surfaces and boxes should also be used for source modelling. In the design process the computer model offers a handful of tools like grid maps of noise distribution, reverberation time, spatial decay rate, identification of the most important sources, and possible effects of various noise control measures. Even the effect of sound insulating structures may be simulated. The methods and possibilities are demonstrated through a case of a large turbine hall with two turbines, each modelled by 17 surface sources and two point sources. The reliability of the computer modelling is confirmed by comparison of calculated and measured sound pressure levels.

INTRODUCTION

Room acoustic modelling technique and especially the room acoustic computer models have developed over the last decades [1] and highly accurate prediction models are available today. Although the room acoustic modelling technique has originally been devoted to the acoustic prediction and design of auditoria, the problems are equally challenging in work rooms, and to a great extent the same methods can be adopted. One fundamental problem is that the rooms can be very irregular, the diffusion of sound can be uneven and very different from the simple assumption of a diffuse sound field, and the sound absorption can be very unevenly distributed over the surfaces; all together this means that the reverberation time cannot be calculated by the classical equations of Sabine and Eyring. An efficient solution to this problem using a computer model is the global decay calculated from particle tracing as originally suggested by Schroeder [2] and later implemented as one of the methods in the ODEON software [3].

Another problem is that even if the reverberation time can be measured and predicted, it may not be the most relevant parameter to describe the acoustical condition of a work room. Using a computer model, Ondet and Sueur [4] found that the slope of the spatial decay curve calculated with a single omni-directional sound source could provide a better basis for an acoustical evaluation in typical non-diffuse work rooms.

During the development over the recent years several other methods have been added, the calculation speed has been dramatically increased, and the accuracy of the predictions have improved. The possibilities in relation to noise control in indoor environments with the room acoustic computer modelling software ODEON will be outlined in the following using a turbine hall as an example [5].

ROOM MODELLING

Room geometry

The first step in the room acoustic modelling is to create the room geometry in a 3D model. The example is a large turbine hall with the main dimensions: 153 m, 34.5 m, and 20 m. The hall contains two turbines, one of which is seen on the photo in Fig. 1. A view from the same angle in the computer model is seen in Fig. 2 and a wireframe model of the entire hall is seen in Fig. 3. It can be noted that the model is much simpler and rough, many details being omitted. This simplification of the geometry is generally allowed because the wavelength of the sound of interest is typically up to several meters (e.g. the wavelength is 2.75 m at 125 Hz).

Figure 1: Turbine hall used as an example of room acoustic modelling.

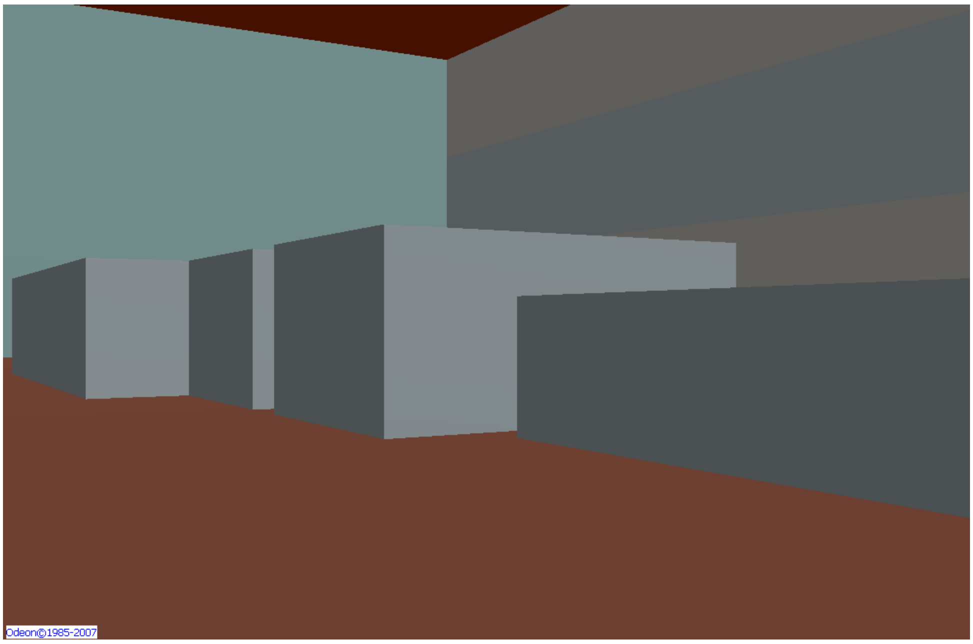

Figure 2: A view into the acoustical model of the turbine hall. The colours indicate different absorption data for the surfaces.

Fig. 3 shows twelve receiver positions that were used for measuring the sound pressure level in the hall, and the same positions were used for calculations in the model. A single source position is also shown; this is used for calculation of the reverberation time and other room acoustic properties in the model as explained below.

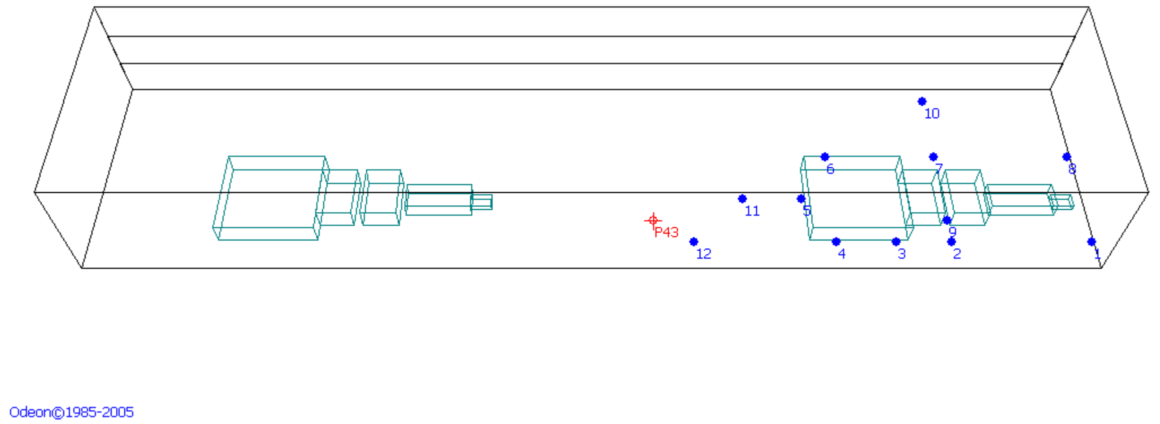

Figure 3: Wireframe model of turbine hall with two turbines roughly modelled. Twelve receiver positions and a single source position have been inserted.

Materials and sound absorption

The material data used for the calculations were based on material descriptions and known absorption coefficients for similar materials. The frequency dependent absorption coefficients are shown in Fig. 4 for eight octave bands. The values at 63 Hz and 8000 Hz have been extrapolated.

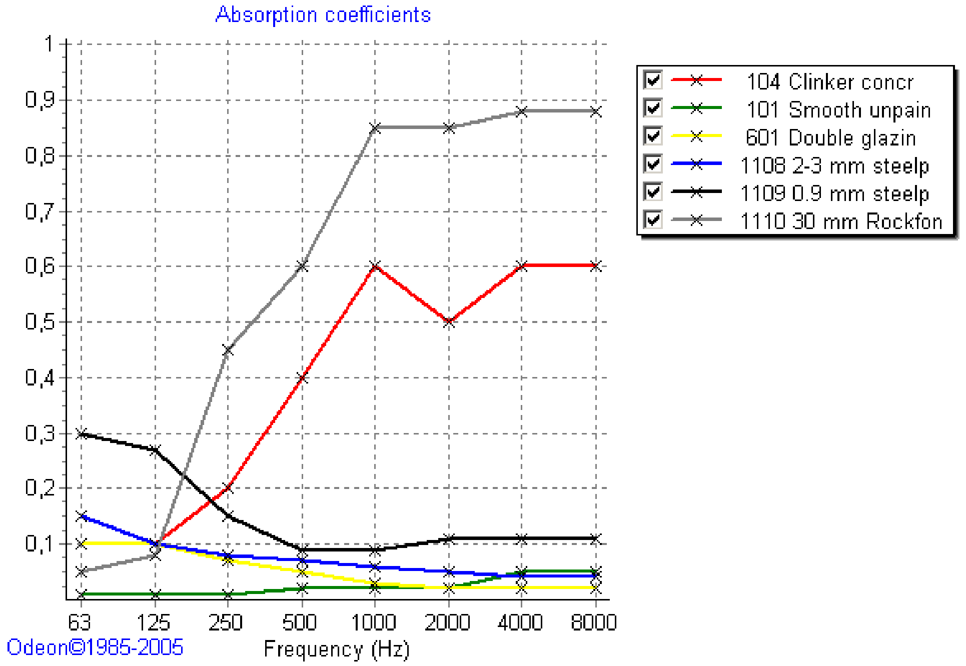

Figure 4: Absorption coefficients of the surfaces as used in the model.

The following six materials were applied:

- Smooth unpainted concrete
- Clinker concrete, no surface finish, 800 kg/m3
- 0.9 mm steel plate with damped cavity
- 2 – 3 mm steel plate with damped cavity
- 30 mm mineral wool (Rockfon) direct on concrete
- Double glazing, 2 -3 mm glass, 10 mm cavity

The reverberation time of the hall was not measured. In case the reverberation time had been available, it would have been possible to adjust some of the absorption data in order to obtain a good fitting to the calculated reverberation times. However, in this example the acoustic simulations are only based on the material descriptions, as would also be the case for a design project.

Surfaces and sound scattering

The sound scattering due to surface roughness and edge diffraction plays an important role in room acoustic simulations. However, in this example no special considerations were made; the reflection based scattering method in ODEON 8.5 and the default scattering coefficient of 0.05 at 707 Hz were applied to all surfaces. The reflection based scattering method is frequency dependent and automatically takes into account scattering occurring due to geometrical properties such as surface size, path lengths and angle of incidence.

ROOM ACOUSTIC RESULTS

Reverberation time

The first question concerning the acoustics of a hall is often the reverberation time, although this may not be the most appropriate acoustical descriptor in case of large industrial halls, as will be discussed below. However, even in a very difficult acoustical environment, i.e. in a room that is far from obeying the assumptions of a diffuse sound field, ODEON offers a quick and very efficient calculation method for the reverberation time, the so-called global decay. In principle it is the method of particle tracing originally proposed by Schroeder [2], but further improved with the vector-based scattering method for sound reflections.

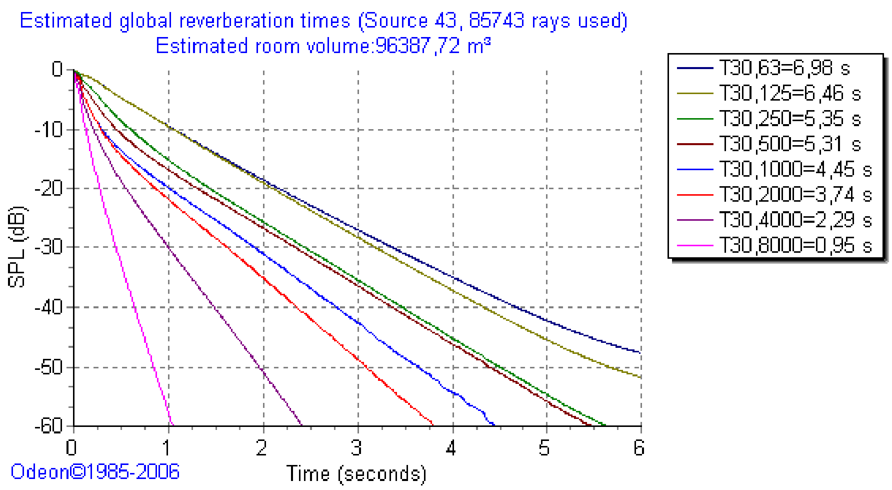

Figure 5: Global decay curves calculated for eight octave bands. The derived reverberation times are listed in the box to the right

Thousands of particles emitted in all directions from the sound source carry a certain amount of sound energy, which is reduced at each reflection according to the absorption coefficient of the surface. Thus, the total amount of energy in the room is calculated in small time steps, and the gradual decrease of the energy in the room can be displayed as a decay curve, see Fig. 5. The great advantage of this method is that it takes the room geometry and the distribution of the sound absorption into account. Thus, the calculated decay curves may not be straight lines, and in that case the reverberation time is slightly different if the evaluation range is taken as 20 dB instead of 30 dB, as seen in the example Fig. 6.

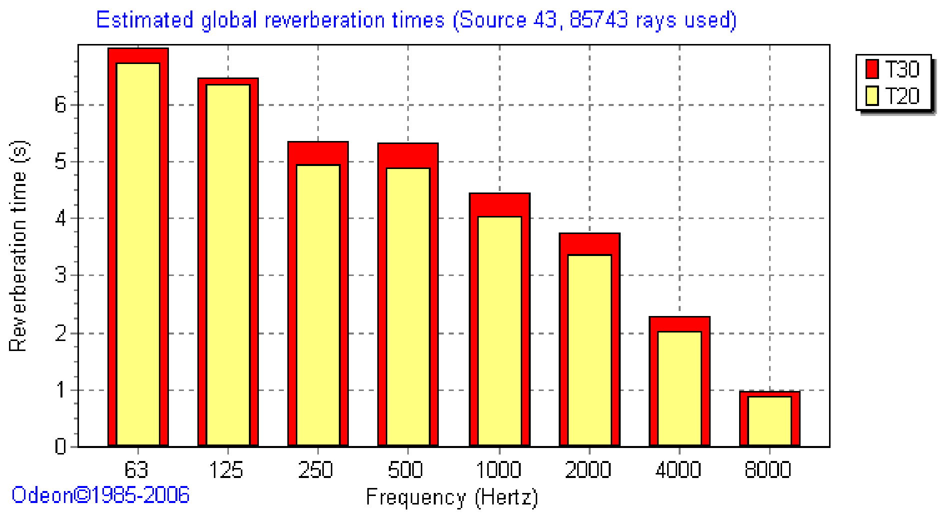

Figure 6: Reverberation times T_{30} and T_{20} derived from the global decay curves in Fig. 5.

Spatial decay

In stead of the reverberation time, Ondet and Sueur [4] found that the slope of the spatial decay curve calculated with a single omni-directional sound source could provide a better basis for an acoustical evaluation in typical non-diffuse work rooms. This method has been described in detail in EN ISO 14257 [6], and with a computer model it is simple to simulate this measurement procedure.

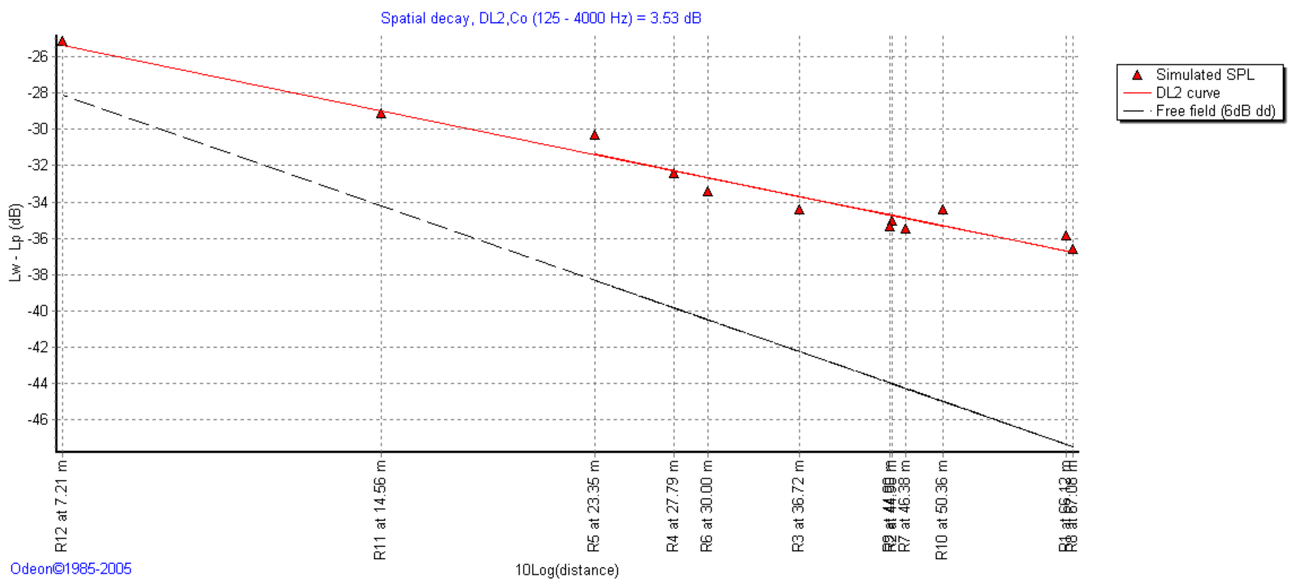

Figure 7: The spatial decay curve calculated for the omni-directional source and the 12 receivers shown in Fig. 3. The frequency averaged slope is DL_2 = 3.53 dB per distance doubling.

An example of a simulation is shown in Fig. 7, using the source and the 12 receivers shown in Fig. 3. Although the receivers should preferably be located on a straight line and have certain distances from the source, the method may also give a useful result using a more random location of the receivers as in this example. The slope is characterised by the attenuation per distance doubling, DL_2. This can be determined in each octave band, and the result presented in Fig. 7 is calculated from the six octave bands 125 Hz – 4000 Hz assuming A-weighted pink noise. For work rooms a value greater than 3 to 4 dB is recommended, see EN ISO 11690-1 [7].

SOURCE MODELLING AND RESULTS

Source modelling

In work rooms and industrial halls the typical noise sources are big and complicated. Thus, for a good simulation it is not possible to use only point sources, as usual in auditorium acoustics. In stead the geometry of the noise sources should be approximately modelled, and the surfaces should be used as sources radiating sound. In Fig. 8 is shown how one of the turbines has been modelled using 17 surface sources and two point sources. Line sources are also available in ODEON. In this example the radiated sound power was measured using intensity measuring technique, so each surface in the model could be assigned a certain radiated sound power in octave bands. Further details are given in [5].

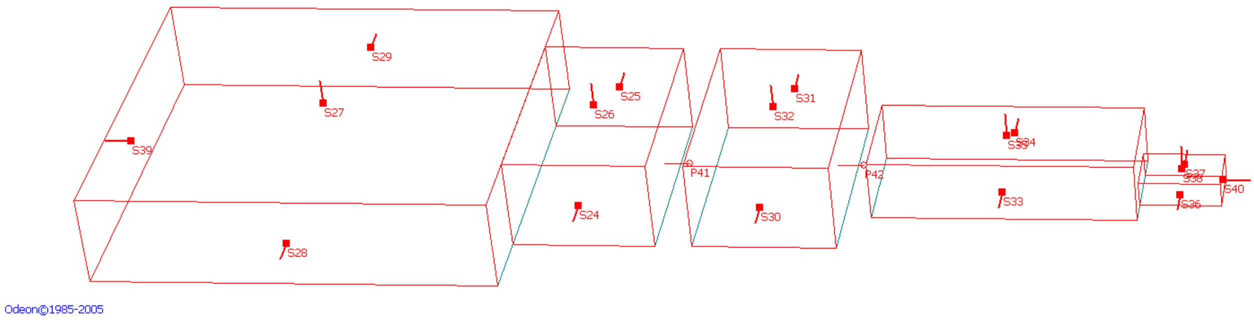

Figure 8: One of the turbines modelled by 17 surface sources and 2 point sources. Each source is assigned a sound power level in octave bands.

Sound pressure level in selected points

The A-weighted sound pressure had previously been measured in the turbine hall in the 12 positions shown in Fig. 3. A similar calculation was made with the computer model with in total 34 surface sources and four point sources. The calculation results are compared to the measured results in Fig. 9, and good agreement can be observed. The average difference is 0.3 dB and the maximum deviation is 2.2 dB in position 12.

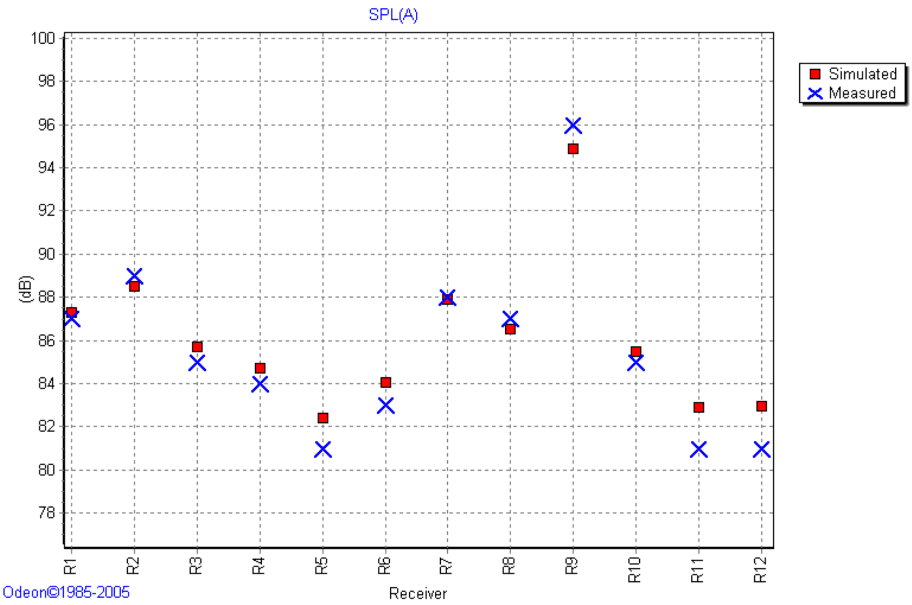

Figure 9: Comparison of calculated and measured A-weighted sound pressure levels in the 12 receiver positions.

TOOLS FOR NOISE CONTROL

Grid mapping of sound pressure level

One very useful feature of a room acoustic computer model is the possibility to calculate the sound pressure in a large number of receiver positions and display the result in a grid map as shown in the example Fig. 10. In this case with 38 sources and 5202 receivers the calculation time is several hours, so this kind of calculations are typically made over night.

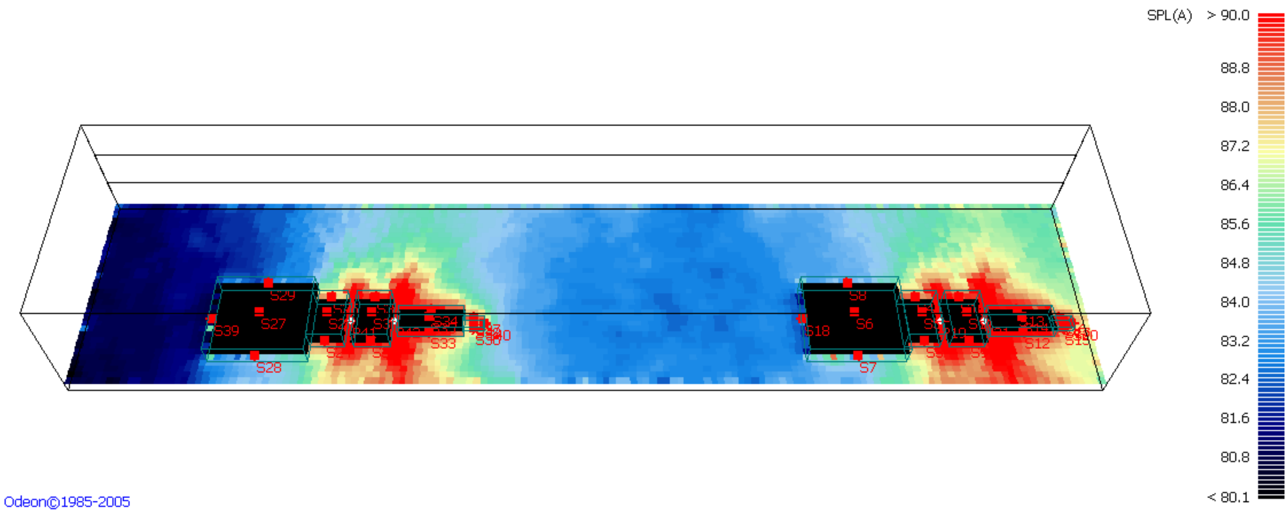

Figure 10: Mapping of the A-weighted sound pressure level with both turbines active. The grid size is 1 m and the height is 1.5 m above the floor.

Ranking of noise sources

Another very useful tool is to display which sources contribute most to the total sound pressure in a certain receiver position. This tool also allows a quick analysis of the possible effect of attenuating certain noise sources, simply by turning one source off and look at the new result.

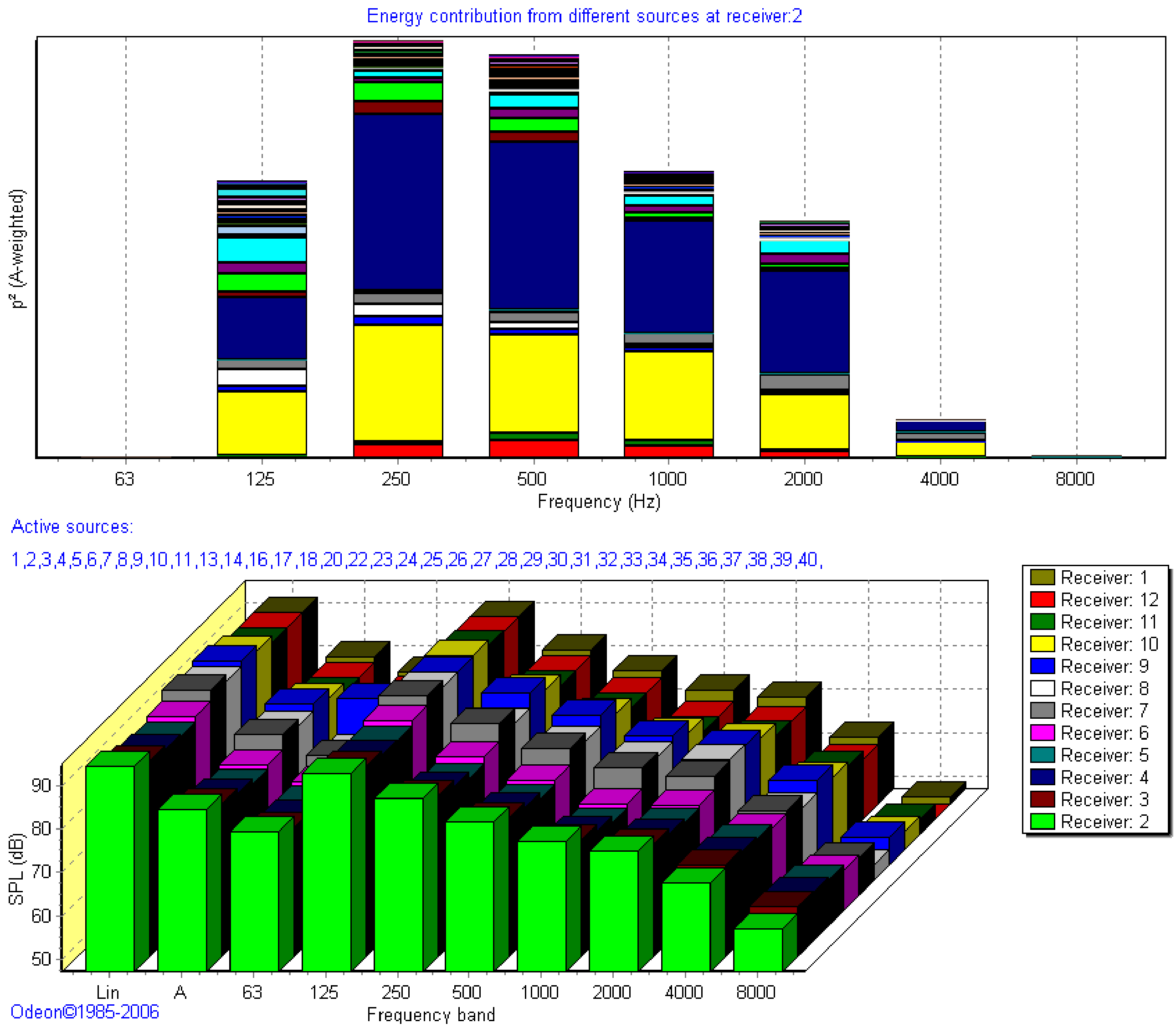

Figure 11: Above - Analysis of the sound sources' contribution to the sound energy in receiver 2. Below - Display of the sound pressure level (Linear, A-weighted and eight octave bands) in the 12 receiver positions.

FURTHER POSSIBILITIES

Auralisation

Auralisation is the technique to make audible the results of a room acoustic simulation. As input is required a recording of the sound generated by the sound source, but free from any reflections and reverberation. This method has been used as an efficient tool in the study of speech privacy in open plan offices, see [8].

Sound transmission

The calculation method applied in ODEON is particularly good for complicated room geometries like coupled volumes. Recently, the ODEON modelling software has also included the option of sound transmission through surfaces, e.g. walls and doors, taking the frequency dependent sound reduction index into account, see ‘What is new in ODEON 9.0’ [9]. Especially in combination with the auralisation tool this opens for new advanced applications in relation to the design for low-noise environments.

CONCLUSION

The room acoustic computer modelling technique has developed to become a very efficient tool for design and planning for low noise and good acoustical conditions in work environments, ranging from noise problems in large industrial halls to speech privacy in open plan offices. The tools include quick and reliable estimates of reverberation time, noise mapping in a certain height above the floor, calculation of the spatial decay rate, ranking of the most important noise sources, and the option of auralisation of a certain scenario.

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