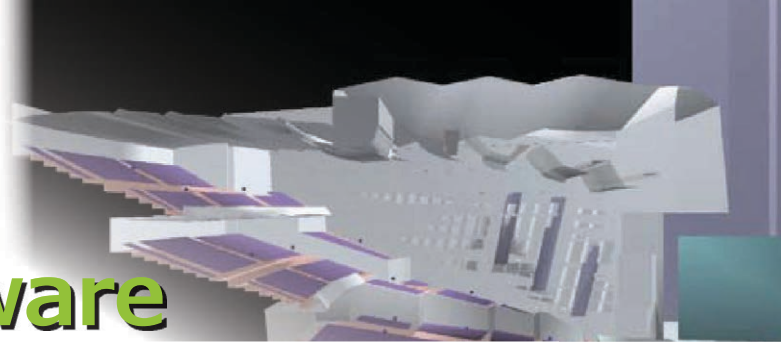
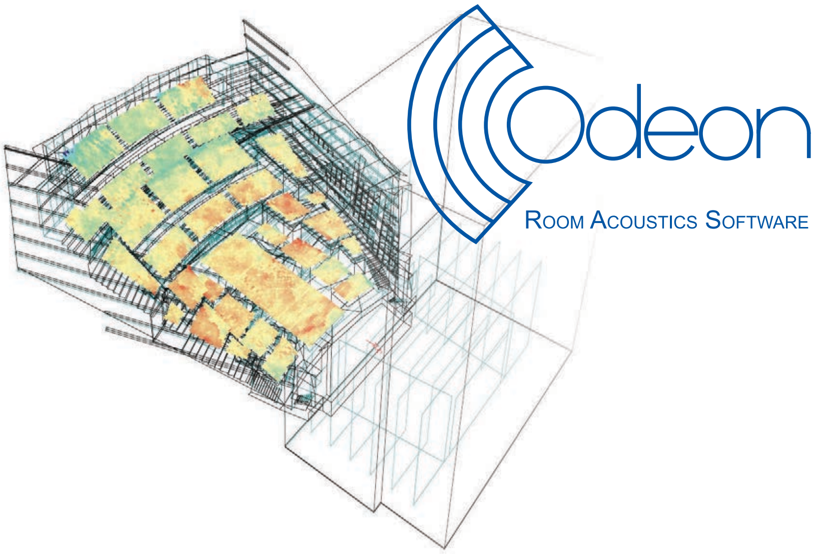


ODEON Room Acoustics Software

This article details the software developed during the ODEON project, which began in 1984 as a collaboration between the Technical University of Denmark and a group of consulting companies. The purpose was to provide reliable prediction software for room acoustics. ODEON's first ray-tracing versions were targeted at solving acoustic problems in concert and opera halls.



By
Richard Honeycutt
(United States)

Author's Note: In this article, "Odeon" refers to the company and "ODEON" refers to the software.

In 1989, Odeon introduced hybrid models, combining cuboid-net-method ray tracing with image source methods (applied differently for early and late reflections) for more reliable results and faster calculation. In 1991, Odeon officially released ODEON V. 1.0, along with a comparison against data measured at the Royal Festival Hall in London.

Improved calculation methods and analysis capabilities, as well as auralization, were added to ODEON during the early 1990s. The current V. 12 incorporates an impulse response measurement system integrated in the software enabling easy comparison of calculated and measured responses. This addition to the software eases tuning models of real spaces to match their actual performance.

ODEON's Materials List

The user can enter model geometry into ODEON via the built-in extrusion modeler. The application allows drawing 2-D surfaces on a selected plane that can be extruded to provide a 3-D geometry directly recognized in ODEON. The application supports layers. When different extrusion planes are required for a complex model, the user can create a different file—one for each extrusion plane—and

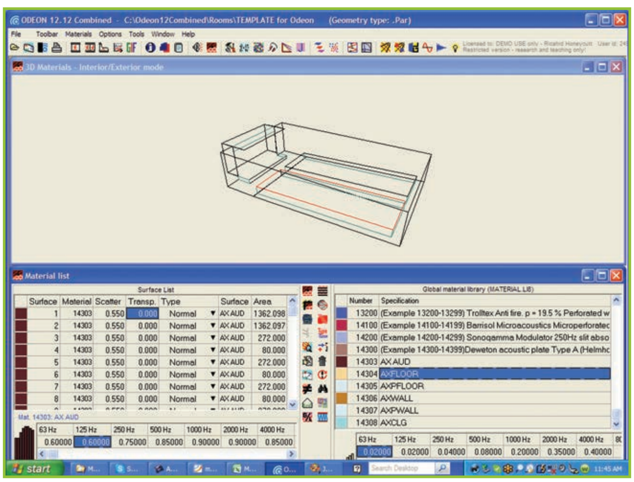


Photo 1: The material list is used to assign materials.

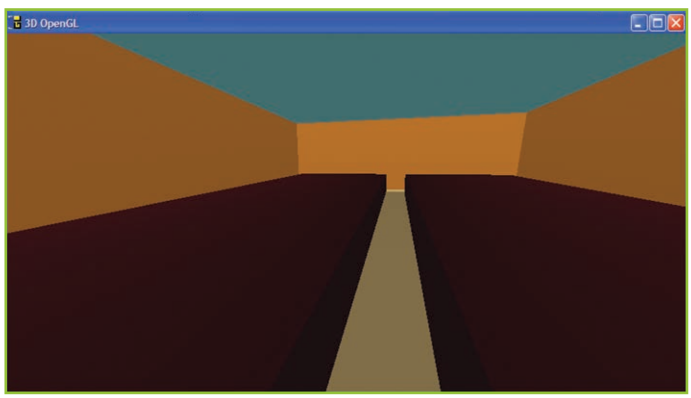


Photo 2: The 3-D Open GL view shows the modeled room by colors related directly to the assigned materials.

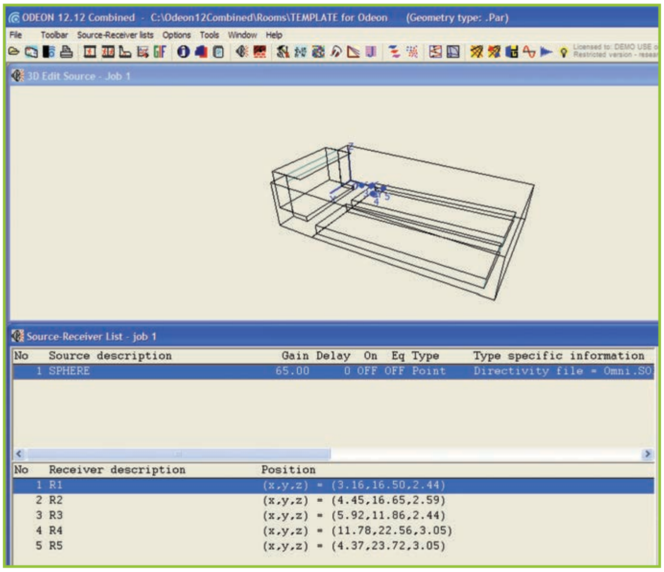


Photo 3: Sources and receivers are entered directly into the Source-Receiver List.

Parameters Plotted vs. Frequency				
EDT	T15	T20	T30	Curvature (C)
Ts	SPL	A-weighted SPL	D50	C7
C50	C80	U50	U80	LF80
LF-C80	Diffusivity	Echo-Dietsch		

Table 1: ODEON can plot several acoustical parameters vs. frequency.

Wideband Parameters				
Unweighted SPL	A-Weighted SPL	C-Weighted SPL	STI	STI Female
STI-male	RASTI	SPL expected	T30 average	LF80 average
Lj average	Bass ratio	SIL	AI	ALcons (from STI)
Reflection density	IACC	Early stage support	Late stage support	Total stage support

Table 2: ODEON also plots wideband parameters.

combine them into a single one.

ODEON can also import model geometry from .dxf, .3ds, and SketchUp files. (SketchUp imports require a plug-in that is freely available from www.odeon.dk). Alternatively, a model can be entirely built using the geometric modeling commands available in the ODEON editor.

After the model has been entered, it will appear on the screen in a wireframe view. Material for the surfaces in the model can be chosen via a Materials List screen (see **Photo 1**). ODEON includes a fairly comprehensive materials list, cataloged by type: simple absorbers, brick, ceramic tiles, wood, audiences, and so forth. The user can also create and use custom materials or material libraries.

The scattering coefficients for all materials are also available on the Material List, but only the midband scattering (average of 500 Hz and 1 kHz bands) is entered. ODEON calculates scattering in the other bands, weighting low-frequency values lower than high frequency values. Scattering is applied by the surface, not by the material.

With the materials entered, the user can view the open graphics library (OGL) rendering of the model (see **Photo 2**). Colors are derived according to the average reflectance of materials, following this RGB color model throughout the audible frequency range: red for low frequencies, green for mid frequencies, and blue for high frequencies, corresponding to the type of frequency range of light. Each color family is varied from black to white for 0% to 100% reflectance, respectively. High absorption at high frequencies leads to “warm” colors, while high absorption at low frequencies leads to “cool” colors.

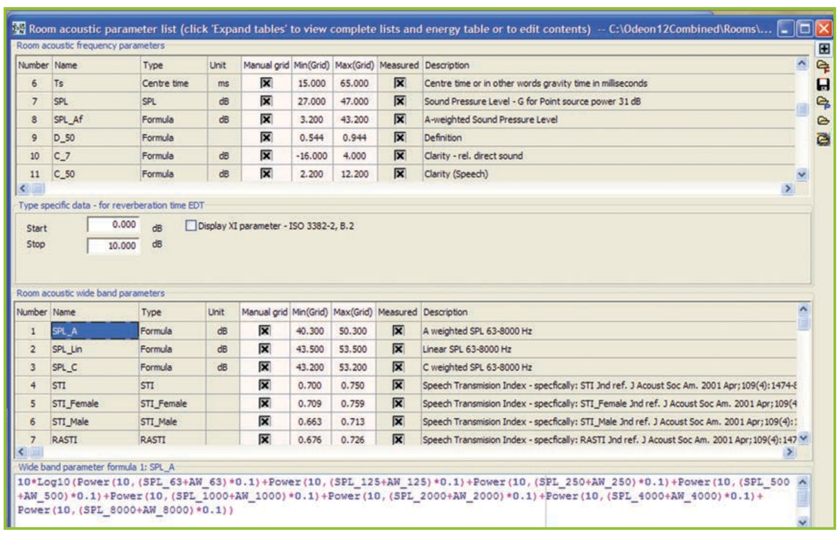
Analysis Preparation

The user can enter sources and receivers into the Source-Receiver List (see **Photo 3**). Use the X, Y, and Z coordinates to specify position. ODEON includes a spherical source that can be used for real-time (RT) calculations, plus a directory structure into which manufacturer-provided files can be downloaded. The default list includes files for normal speech, musical instruments, and known loudspeaker manufacturers. ODEON can accommodate .So8, CLF (CF1 and CF2), and XML files for beam-steered arrays. It does not use generic loudspeaker libraries (GLLs).

With the geometry entered, the materials assigned, and the sources and listener positions defined, the model is complete and ready for analysis. ODEON calculates an impressive array of acoustical parameters (see **Table 1** and **Table 2**).

For each analysis, the user can select the desired parameters via the Room Parameters List dialog (see **Photo 4**). Any parameter can be modified and new ones can be formulated. The Room Parameters List dialog shows the equation with which each selected parameter is calculated.

Photo 4: The user can choose the desired parameters for calculation via the Room Acoustic Parameter list.



Calculations

ODEON performs three types of calculations: single-point response, multi-point response, and grid response. The first two types of calculations provide results for specific listener positions. The grid response provides mapping data for a grid defined by the user. The user can control the way the calculations are performed via the Room Setup panel. Specific point response, multi-point responses, or a grid response can be run separately or as a batch, via the Job List (see **Photo 5**). Buttons on the Job List also display the calculation results.

ODEON treats scattering in different ways, depending on the distance from the source to the scattering reflector. Since by default ODEON automatically introduces scattering, according to the reflection-based scattering method, there will always be a reasonable degree of scattering in the simulation. Special scattering coefficient values are only required when the surface's geometry is simplified (e.g., when an audience area is modeled as a simple box, a 60% scattering should be specified to compensate for the lack of detail). Diffraction is automatically applied at the first and second reflection points, if applicable. Diffraction is treated by analytical formulae around a single edge (one-point diffraction) or two subsequent edges (two-point diffraction). Both cases occur only for the direct sound—not for reflections—on the assumption that in room acoustics, diffraction from reflections is much less important than diffraction from direct sound.

By default, ODEON uses the Image response method up to second-order reflections. Users can specify that image sources be used up to the 10th order. The order of image sources used in a calculation is called the transition order. Reflections up to this order comprise the early response. Subsequent calculations detail the late response. An algorithm called receiver-independent ray tracing (ray-radiosity) is applied, in which rays are transmitted all over the room. Secondary sources are placed at reflection points for all rays. A secondary source has

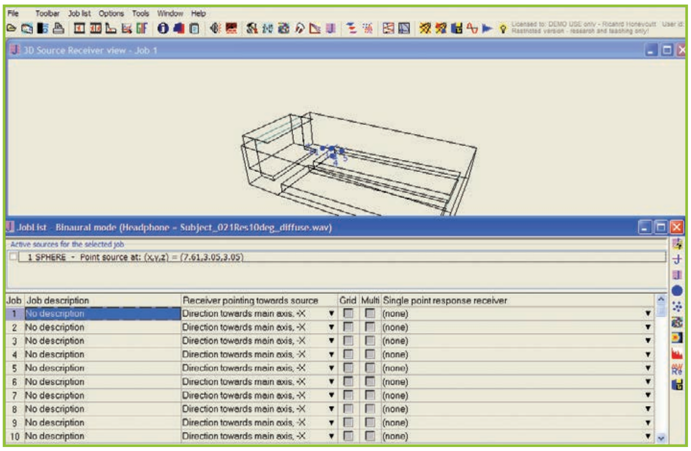


Photo 5: The Job List is the control point for selecting analyses to perform or results to display.

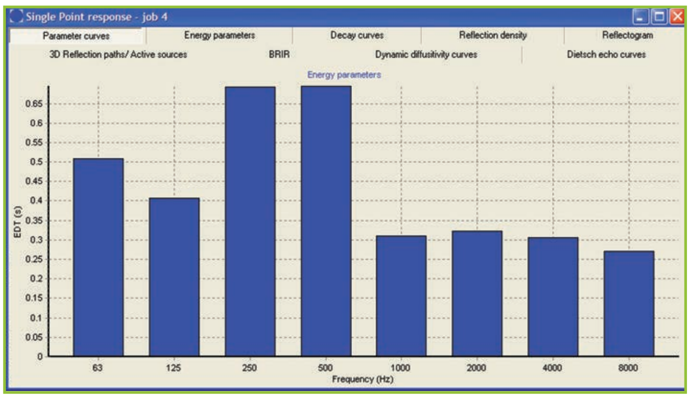
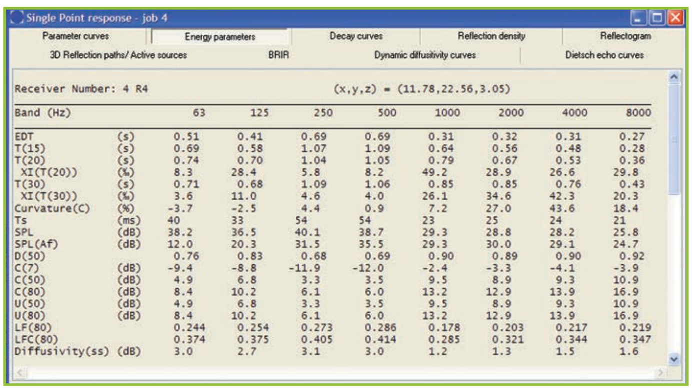


Photo 6: This single-point response shows EDT vs. frequency.



Receiver Number: 4 R4   (x,y,z) = (11.78,22.56,3.05)

Band (Hz)		63	125	250	500	1000	2000	4000	8000
EDT	(s)	0.51	0.41	0.69	0.69	0.31	0.32	0.31	0.27
T(15)	(s)	0.69	0.58	1.07	1.09	0.64	0.56	0.48	0.28
T(20)	(s)	0.74	0.70	1.04	1.05	0.79	0.67	0.53	0.36
XI(T(20))	(‰)	8.3	28.4	5.8	8.2	49.2	28.9	26.6	29.8
T(30)	(s)	0.71	0.68	1.09	1.06	0.85	0.85	0.76	0.43
XI(T(30))	(‰)	3.6	11.0	4.6	4.0	26.1	34.6	42.3	20.3
Curvature(C)	(%)	-3.7	-2.5	4.4	0.9	7.2	27.0	43.6	18.4
Ts	(ms)	40	33	54	54	23	25	24	21
SPL	(dB)	38.2	36.5	40.1	38.7	29.3	28.8	28.2	25.8
SPL(Af)	(dB)	12.0	20.3	31.5	35.5	29.3	30.0	29.1	24.7
D(50)		0.76	0.83	0.68	0.69	0.90	0.89	0.90	0.92
C(7)	(dB)	-9.4	-8.8	-11.9	-12.0	-2.4	-3.3	-4.1	-3.9
C(50)	(dB)	4.9	6.8	3.3	3.5	9.5	8.9	9.3	10.9
C(80)	(dB)	8.4	10.2	6.1	6.0	13.2	12.9	13.9	16.9
U(50)	(dB)	4.9	6.8	3.3	3.5	9.5	8.9	9.3	10.9
U(80)	(dB)	8.4	10.2	6.1	6.0	13.2	12.9	13.9	16.9
LF(80)		0.244	0.254	0.273	0.286	0.178	0.203	0.217	0.219
LFC(80)		0.374	0.375	0.405	0.414	0.285	0.321	0.344	0.347
Diffusivity(ss)	(dB)	3.0	2.7	3.1	3.0	1.2	1.3	1.5	1.6

Photo 7: A tabular display of parameter values is also available.

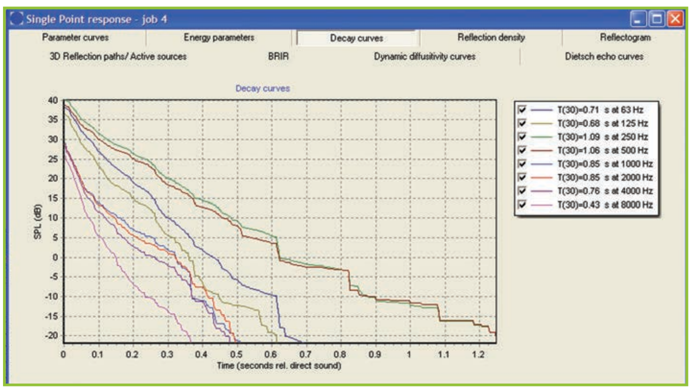


Photo 8: Sound pressure level (SPL) decay curves are plotted for each octave band.

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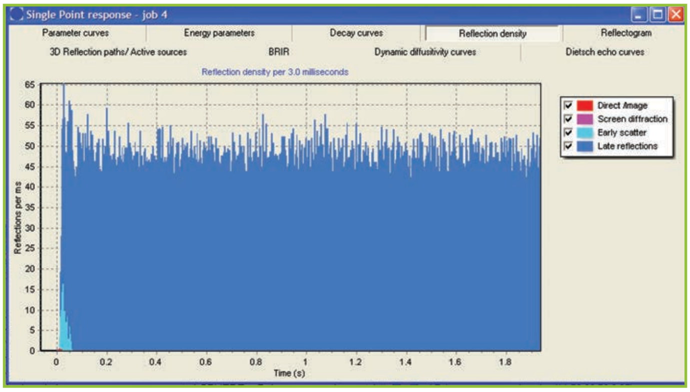

Photo 9: The reflection density plot shows the number of reflections per 3 ms plotted vs. times.

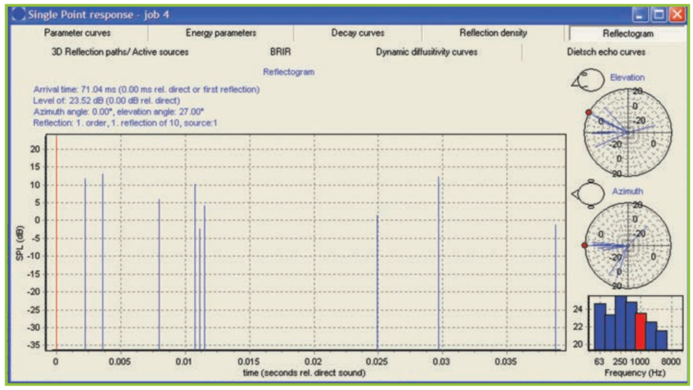

Photo 10: The reflectogram shows individual reflection arrival times.

an associated delay and strength. If a secondary source is visible from a receiver, the corresponding energy pack is added to the impulse response for that particular receiver. In this way, the impulse response for another receiver can be rapidly calculated from the same group of secondary sources, without the need to repeat the ray-transmission process. In addition to ray tracing, ODEON calculates RT by three statistical methods: Sabine, Norris-Eyring, and Puchades.

Responses

The results of the single-point response are presented in various ways, controlled by the tabs at the top of the panel shown in **Photo 6**. The Parameter Curves tab provides bar graphs showing the values of the various calculated parameters plotted vs. frequency. Use the right- and left- arrow keys to select the particular parameter being plotted.

Parameter values can also be displayed in tabular format (see **Photo 7**). The third tab of the single-point response panel shows sound pressure level (SPL) decay in each octave band (see **Photo 8**). The fourth tab presents a plot of reflection density (see **Photo 9**). Such a plot is useful in determining whether enough rays have been used for the calculations. At least 30 reflections per millisecond are required to ensure the room geometry's details have been correctly sampled for a reliable simulation. The reflectogram shown in **Photo 10** provides a detailed view of individual reflection arrival times. The reflection path from source to receiver is helpful in identifying surfaces that may need absorptive or diffusive treatment (see **Photo 11**).

Although the binaural impulse responses are primarily used to create auralizations, they can also be viewed via the BRIR tab (see **Photo 12**). The Dynamic Diffusivity Curves tab in the single point response panel can be used to examine the variation of sound diffusion in the room as the decay progresses. Echo disturbance, calculated by the Dietsch and Kraak method, is graphed vs. time, which is accessed via the Dietsch Echo Curves tab.

The multi-point response analysis provides stacked bar graphs of the energy parameters plotted vs. frequency, if the Energy Parameters (1) tab is selected on the multi-point responses panel (see **Photo 13**). The wideband values of the parameters are shown via the Energy Parameters (2) tab. Use the right- and left-arrow keys to select the specific

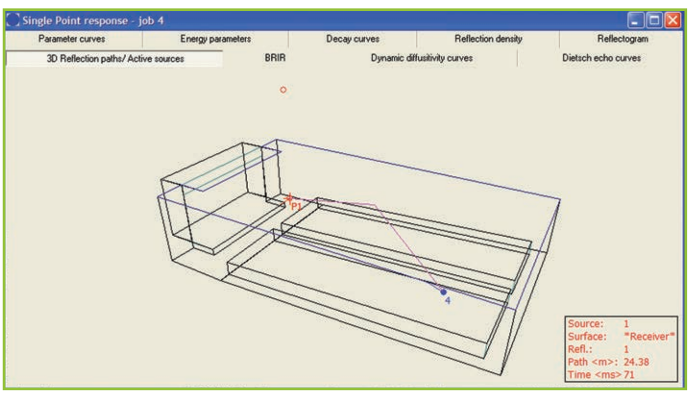

Photo 11: The path of each reflection can be displayed.

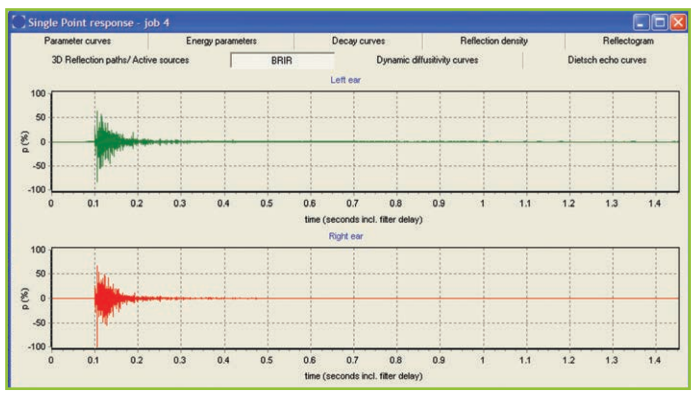

Photo 12: The binaural impulse responses for each ear can be viewed.

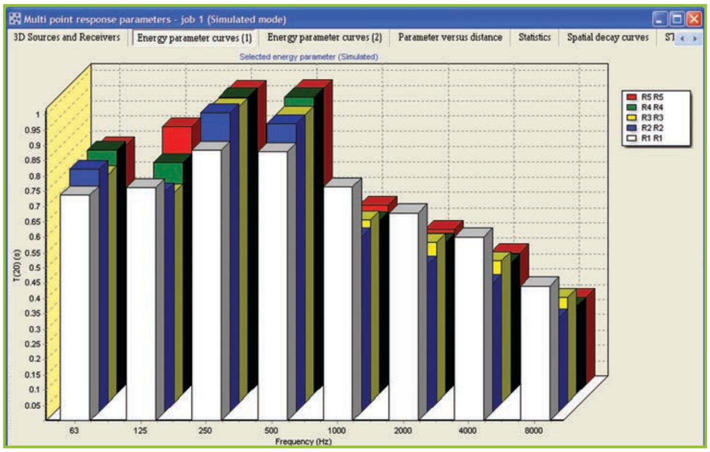

Photo 13: Values of each energy parameter at each receiver are plotted vs. octave band.

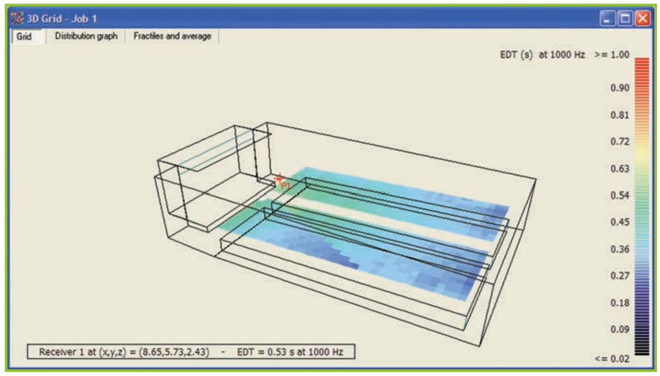

Photo 14: The grid response function provides parameter mapping.

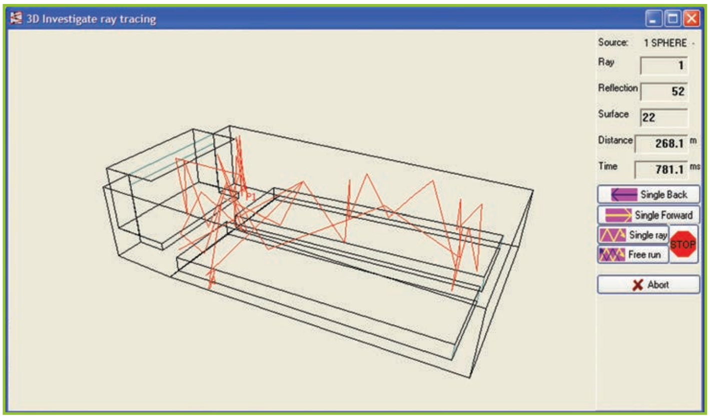

Photo 15: The 3-D Investigate Rays assists in visualizing ray paths.

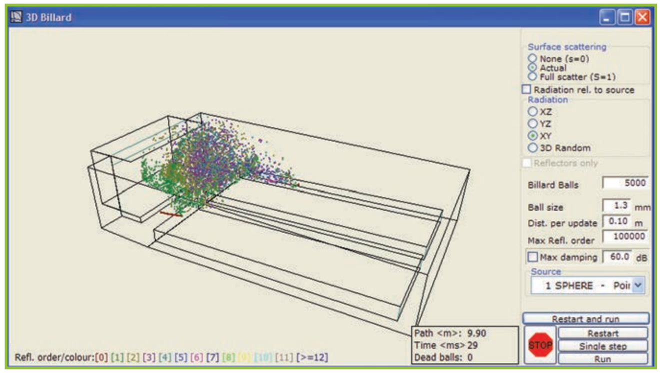

Photo 16: The 3-D Billiard animation shows how wavefronts progress through the room.

parameter to be graphed. The other three tabs on the multi-point display panel are self-explanatory.

The grid analysis provides maps of the selected parameters across a user-defined grid. As an example, **Photo 14** shows the early decay time (EDT) map for the sample we have analyzed. Use the left- and right-arrow keys to select other parameters. The up- and down-arrow keys can be used to change the displayed octave band.

In addition to the single-point , multi-point, and grid response panels, three buttons activate specific displays. The 3-D Direct response button on the Job List shows the mapped direct SPL. The 3-D Investigate Rays button on the main toolbar enables the user to see the progress of rays as they propagate through the venue.

Photo 15 shows how this helps visualize the paths of both helpful and detrimental reflections. The rays can be added one at a time or the display can be set to free-run. This display is useful for locating holes in the model. Although (unlike some programs) ODEON can run with small leaks, calculations are terminated if ray loss exceeding 20% is found.

The 3-D Billiard display button on the main toolbar brings up a display that represents wavefronts by small "billiard-ball" objects that progress in the room (see **Photo 16**). As for 3-D Investigate Rays, this display is particularly valuable for locating small leaks in the model (which can cause errors) and identifying sources of focused reflections.

ODEON provides online binaural auralization plus offline multichannel convolution with individual adjustment of the delay and level of each channel.

In addition to uses for architectural acoustics, ODEON provides capabilities for evaluation of industrial noise and noise isolation, through its ability to utilize transmission through semitransparent surfaces. Accordingly, ODEON is available in Basic, Industrial, Auditorium, and Combined editions. All versions support International Organization for Standardization (ISO) standards 3382-2 and -3, 14257, and 60268-16. The Auditorium and Combined editions also support ISO 3382-1.

In addition, the Auditorium and Combined editions provide calculations of a number of room acoustic parameters not available in the other versions. The industrial version includes the capability of using line sources (these are different from line arrays) and surface sources. A comprehensive comparison of the Basic, Industrial, Auditorium, and Combined editions, a demo version, and a free trial are available at www.odeon.dk.