ODEON

BASICS INDUSTRIAL AUDITORIUM COMBINED

User's Manual

Odeon
Room Acoustics Software

ODEON Room Acoustics Software
User's Manual
Version 19

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Odeon A/S
DTU Science Park
Diplomvej, building 381
DK-2800 Kgs. Lyngby
Denmark
Tel: +45 8870 8845
Fax: +45 8870 8090
www.odeon.dk

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USE OF ANECHOIC ORCHESTRA RECORDINGS DELIVERED WITH THE SOFTWARE

The ODEON Auditorium and Combined versions (excluding the demo version) are installed with a number of anechoic recordings that may be used with the ODEON software without restrictions. Additional anechoic recordings are available as ODEON zip archives from the ODEON homepage. The zip archives come with a room and relevant anechoic files, which are stored automatically in the ODEON's default *anechoic files* folder. Therefore, they can be used in any other project as well. Every zip archive comes an associated license information as a text file (with the extension Licenses). **It is important to read the license information before using the files. When the room model is loaded into ODEON, the license information file can be opened in the Odeon editor by clicking the notes icon in ODEON.**

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Introduction

Thank you for using ODEON, the Room Acoustic Software package that helps you to make complete studies of room acoustics for any large space through simulations and measurements! We hope you will enjoy working with ODEON and that you will find it extremely useful in the acoustical design of new spaces and improvement of existing ones. ODEON has a very user-friendly interface, which allows setting up a project very fast, and to create elegant presentation of results.

This manual is intended to serve as an introduction on modelling room geometries for the ODEON software, on the features for measurements and simulations, and on the applied calculation principles. It will not cover all features included in the ODEON software in detail; explanations of displays, calculation parameters, results, etc. are available as context sensitive help from within the ODEON application (shortcut F1) – the context sensitive help also include direct links to relevant tutorial videos. It is recommended to use the context sensitive help to learn about the specific features available from the different displays, the interpretation of results, calculation parameters, etc.

A large number of comprehensive tutorial videos are also available from our home page – they can be accessed directly from within ODEON using the Shift+Ctrl+F1 shortcut or by clicking the Video tutorial icon in the ODEON toolbar.

The contents of this manual are as follows:

Chapter 1 covers installation of the program, changes from previous versions, etc.

Chapter 2 covers geometry modelling, with important tips on how to make models for acoustical simulations. It also covers how to import geometry from 3D modelling software, and how to use the 3D modelling tools in ODEON.

Chapter 3 describes types of sources and receivers, how to extend the library of source directivity patterns available for point sources, and the use of directivity patterns in the Common Loudspeaker Format (CLF).

Chapter 4 deals with the acoustic materials to assign to the surfaces of rooms; absorption, scattering and transparency coefficients, as well as transmission data. Special materials that may speed up the modelling process, and how to manage the material library, are also covered in this chapter.

Chapter 5 deals with different calculation options and associated results in the four editions of ODEON.

Chapter 6 describes how to work with Colour Grids.

Chapter 7 deals with the auralisation options in ODEON *Auditorium* and *Combined*; the hardware needed for auralisation, how to publish calculated sound examples, etc.

Chapter 8 describes important calculated room acoustic parameters available in ODEON, how they are calculated, and how to interpret results.

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Chapter 9 introduces the calculation principles used in ODEON, giving an idea on the capabilities and limitations of the simulations performed by the ODEON software.

Chapter 10 describes the various calculation parameters available in the program. Most of the parameters are automatically set to reasonable values by ODEON; However, for special cases you may need to adjust some of the calculation parameters.

Chapter 11 discusses quality of results and how to achieve good results. This chapter may be relevant once familiar with the program.

Chapter 12 presents the integrated impulse response measuring system in ODEON. The chapter explains which measuring methods are used, how to obtain a healthy impulse response and how to obtain room acoustic parameters as the results. The chapter ends with an annex giving examples of good and bad impulse responses.

Chapter 13 describes how to use ODEON's Genetic Material Optimizer for calibrating a room model towards a real room. The Genetic Material Optimizer makes use of genetic algorithms in order to calibrate the materials (absorption coefficients) in the simulation model for good agreement between simulated and measured room acoustics parameters.

Chapter 14 presents ODEON's Source Power Estimation tool which makes it possible to estimate the source power spectrum of sources from real-life SPL measurements.

Chapter 15 describes ODEON's building acoustic module, which can be used to measure a partition wall's reduction index from multiple impulse response measurements.

Chapter 16 introduces the line array sources discussing some basic principles behind array source design.

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1 ODEON Installations

To work with ODEON, you need both an installation of the program on your PC, as well as a hardware key dongle (Rockey 6 Smart – R6 Smart). After purchasing ODEON, you receive the dongle with time limitation. Once full payment is completed, an update file is sent by Odeon A/S that removes the time limitation. The update file needs to be installed by you on the dongle.

1.1 Installing and running the program

To run ODEON, your PC must be running one of the supported operating systems:

- 32 bit/64 bit Windows 11.
- 32 bit/64 bit Windows 10.

ODEON comes in a USB drive containing the edition of ODEON that was purchased (*Basics*, *Industrial*, *Auditorium* or *Combined*). As an alternative, you may download the most recent updated version, including service updates that were developed since the production of the USB. To install the program:

a) Double-click on the file with the name of the edition you wish to install, e.g. InstallOdeon19Combined.exe to install the program.
b) To run the program, the supplied hardware key dongle (Rockey 6 Smart – R6 Smart) must be inserted into the USB port on the PC. If you start the program without the hardware key, it can only be used in viewer mode.
c) When you have installed the ODEON software, it will automatically check for updates. If there are updates available, ODEON will update your installation if you accept.
d) Initially, the dongle ships with a time limitation. Once full payment is completed, send a request to *sales@odeon.dk* to remove the time limitation. You will receive an update file that needs to be installed on the dongle by choosing Tools>Download license update to dongle (.cif).

1.2 Upgrading from previous versions

If you are upgrading from previous versions of ODEON, read below to learn about the changes in ODEON. Below is a list of issues which you should be aware of when upgrading from previous versions.

Upgrading to version 19

ODEON version 19 runs on Windows 10 and 11 (32/64 bit editions). ODEON 19 may be able to run on older versions of Windows (8, 7, Vista), but it has not been tested. These operating systems are unsafe, as they are no longer maintained and supported by Microsoft. ODEON 19 is a major upgrade, please see sec. 1.3. Though ODEON 19 is capable of loading and converting older projects into version 19 format (forward compatibility), an older version of ODEON may not load a room once it has been loaded into ODEON 19. ODEON 19 includes a large number of enhancements – for a fairly complete list see sec. 1.3 or open the help file from within the ODEON software (press F1 from within ODEON, then click the What's new in ODEON 19 entry in the contents-menu).

Remember: If keeping an earlier version, be careful not to mix the use of old and new versions – although we do strive to maintain forward compatibility, we cannot guarantee that a room which has been loaded into a newer version of ODEON will also load into an older version without problems.

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Major upgrade

If performing a major upgrade, typically a full version number or more, e.g. from version 17 to version 18, then ODEON will install to a new directory for that version without changing the existing installation. If you have no wishes to use the old version of ODEON then it is recommended to uninstall the version(s) using the Windows Start|Control Panel|Add/remove programs feature.

If you have been using version 7 or earlier

If you are used to versions earlier than version 8, it is essential to learn about the new methods for handling of scattering. Chapter 4 covers the material properties to assign to surfaces; Chapter 9 covers the calculation principles including handling of scattering and Chapter 10 covers the choice of calculation parameters.

If you are having problems loading a room, which was created and worked fine in an old version of ODEON, this is probably due to a change that has been made to the surface numbering mechanism applied in ODEON. The numbering mechanism has been changed slightly in order to avoid a conflict which appeared when using 'symmetric surfaces', along with modelling entities such as CountSurf, Box, Cylinder etc. and in particular to make the automatic surface numbering work without any problems (when the NumbOffSet is set to Auto).

If having problems loading a room due to the reasons just mentioned, ODEON will either give an error message that surfaces are repeated in the geometry file or that materials are not applied to all surfaces. In these cases you may wish that ODEON uses the old numbering mechanism – this can be done using the Version4 .par file. At the first line in the geometry file, just after the ### sign, type: flag in the Version4 TRUE.

Once the old incompatible code ends, Version4 may be set to FALSE again.

If you have been using a version 6 and earlier

If you are used to a version earlier than 6 then we do recommend that you read carefully through the manual as if you are a newcomer to ODEON. There are substantial differences between the early versions of ODEON and the ODEON software as it is today – modelling has been made easier, calculation principles have been enhanced and a huge number of new features has been added.

Project files from very old versions of ODEON

The only project file from ODEON versions earlier than 3.0, being fully compatible, is the surface file (.sur). The rest of the project files are no longer valid. And even though the .sur format is still valid, it is not recommended to model rooms in this format. The .par format is a much more efficient format.

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1.3 What's new in ODEON 19

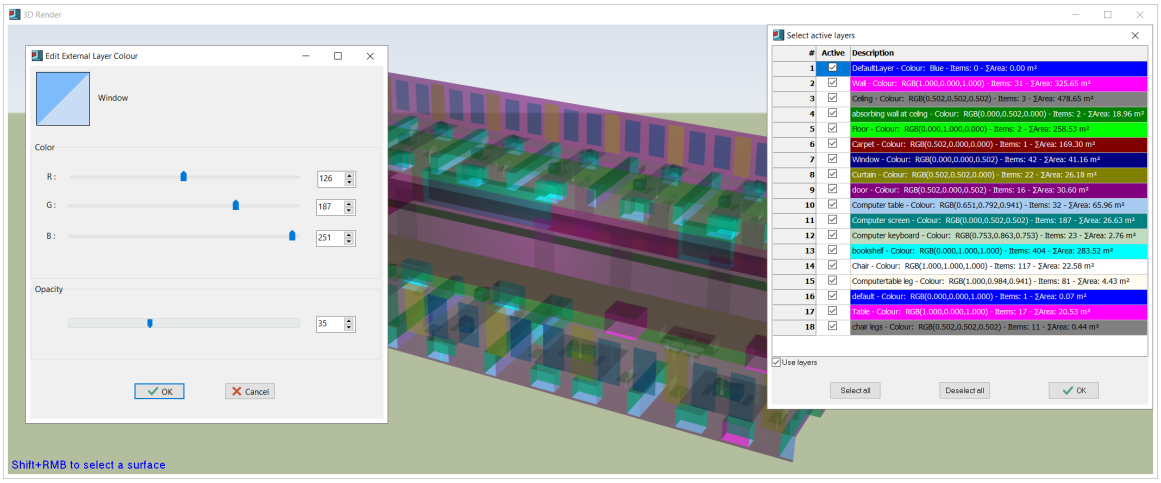
The most recent version 19 has been released in the summer of 2025 and is packed with attractive features and enhancements, listed below. The headings will specify what editions of ODEON: (B) **Basics**, (I) **Industrial**, (A) **Auditorium** and (C) **Combined**, each feature is available in. If not specified, then it is available for all editions.

Remember: The ODEON software is only **forward compatible**. This means that you may load a room that has been created in ODEON 18 (or earlier versions down to ODEON 3.0) into ODEON 19. The opposite is not always the case. Once a room has been loaded into ODEON 19, there might be issues loading it into earlier versions. ODEON 19 will issue a warning before loading a room created in an earlier version - allowing you to make a backup copy for use in an older version of ODEON.

Improved 3D Rendering

The 3D Render menu has been refurbished to provide better graphics, and it includes the following new options:

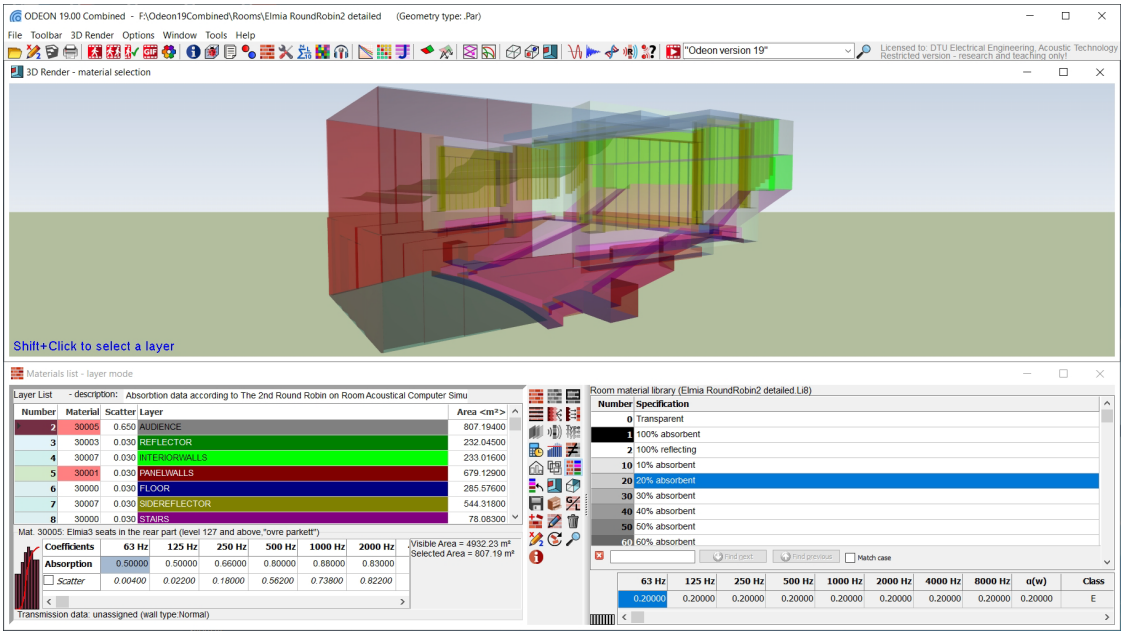
- A horizon line in the background makes it easier to contextualize your model.
- The layer colours can be changed directly within the 3D Render.
- You can set transparency to layers so that windows and glass look more realistic.
- The X-ray option makes all surfaces transparent, so that you can see through the model.
- The 3D render can be used in first-person view to modify source and receiver positions in real time.
- Assets are 2D and 3D objects that can be added to the 3D render for visual purposes (e.g. furniture, people, decoration).



Material list interface

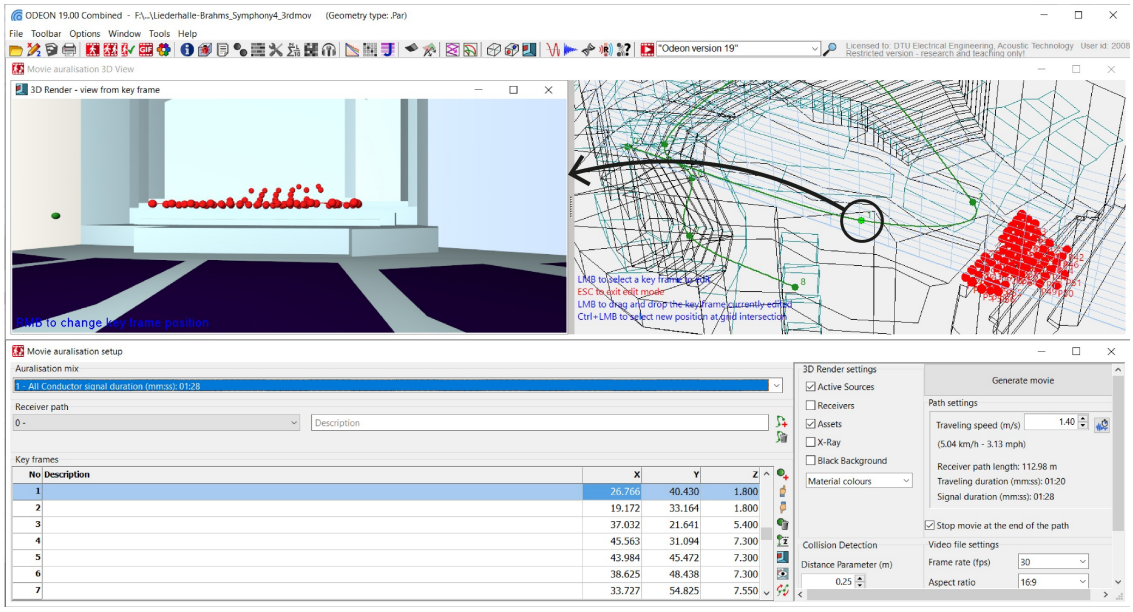
A 3D Render view of the room now shows by default in the material list, either with *X-ray transparency* or *solid surfaces*. It also shows the colours of layers. In the inner view, you can shift-click on surfaces to reveal the surface number. In the outer view, when you shift-click on the model, ODEON will show you all the surfaces that the click goes through. You can always toggle back to the wireframe 3D View.

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Movie Auralisation (A)(C)

Listen to the acoustics in a predefined walking path inside the room. ODEON computes the auralisation following the path, and exports the experience into an MP4 video file that can be shared to anyone. No VR goggles needed!



Improved calculation algorithms.

ODEON can now accept absorption coefficients and carry out calculations in ⅓ **octave bands**. The final results will still be in **full octave bands**. However, calculating internally in ⅓ octave bands allows to find behaviours that happen in frequency bands narrower than full octave bands. If you use materials with coefficients in full octave bands, ODEON will internally interpolate for ⅓ octave bands.

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The ray-tracing can also be split into 2, 4 or 8 bands in order to account for the frequency-dependency of the scattering coefficients. A different set of rays will be used for each band, which will allow for better visibility in complex cases such as coupled rooms.

Frequency-dependent scattering coefficients

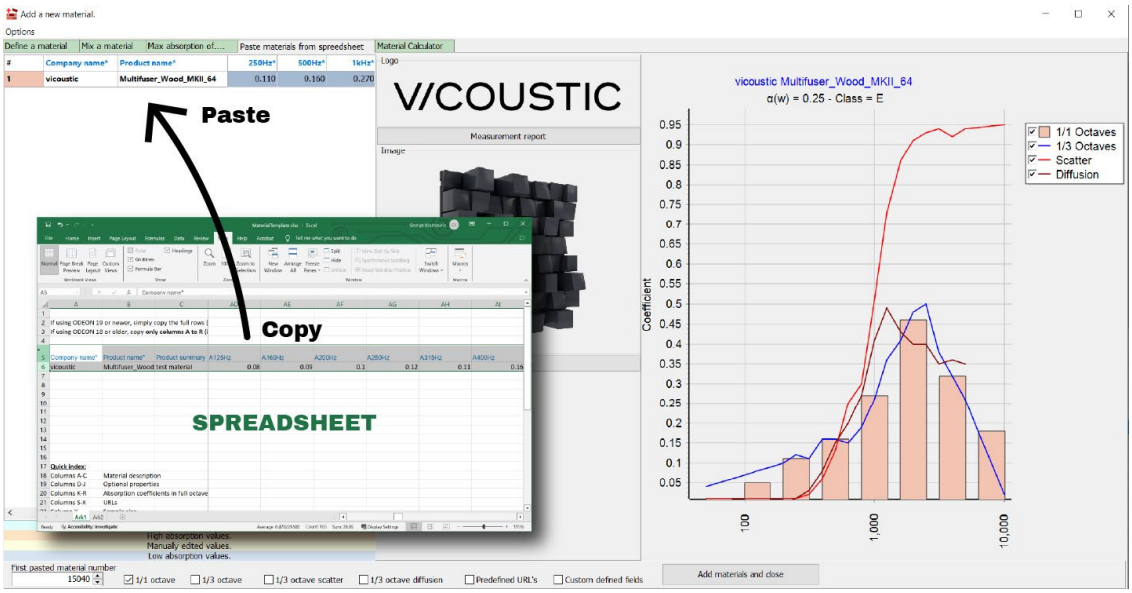
You can now enter your own **frequency-dependent scattering coefficients** for each surface in the **Material list.** You can freely choose to use your own coefficients, or to use our original definition of scattering, where you enter a single coefficient at middle frequencies, and ODEON extrapolates for the whole frequency range. See more in Sec. 4.7.

Mat. 30005: Elmia3 seats in the rear part (level 127 and above,"ovre parkett")

Coefficients	63 Hz	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz	α(w)	Class
Absorption	0.50000	0.50000	0.66000	0.80000	0.88000	0.83000	0.70000	0.70000	0.85000	B
☑ *Scatter*	*0.00400*	*0.02200*	*0.18000*	*0.56200*	*0.73800*	*0.82200*	*0.86600*	*0.88200*		

Improved material import

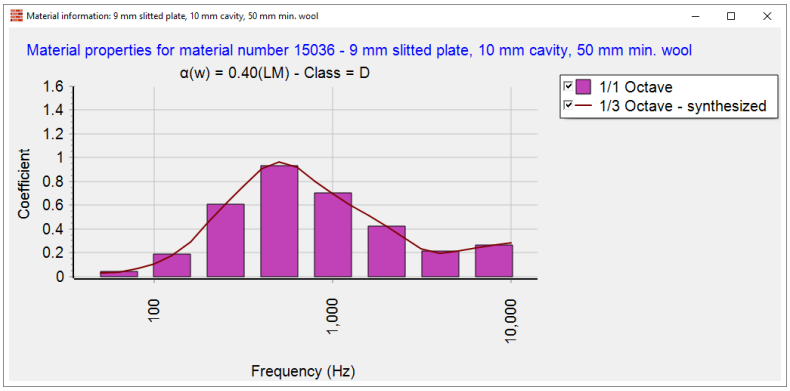
Materials can be easily inserted from a spreadsheet, which is now expanded to import new data, such as 1/3-octave bands absorption, scattering coefficients (see below) picture and links for the material. When you copy the data into ODEON, you will already be able to see the data in a table format.



Information about selected material

You can now toggle a window showing more information about the selected material. You will be able to see the absorption coefficients in full octave bands, as well as absorption and scattering coefficients in 1/3 octave bands if you provided them. If absorption coefficients in 1/3 octave bands were not provided, ODEON will estimate them by interpolating from the values at full octave bands. If the manufacturer has provided the data, you may also see the company logo, picture of the material, and buttons for documents such as the measurement report.

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& Automatically generate jobs

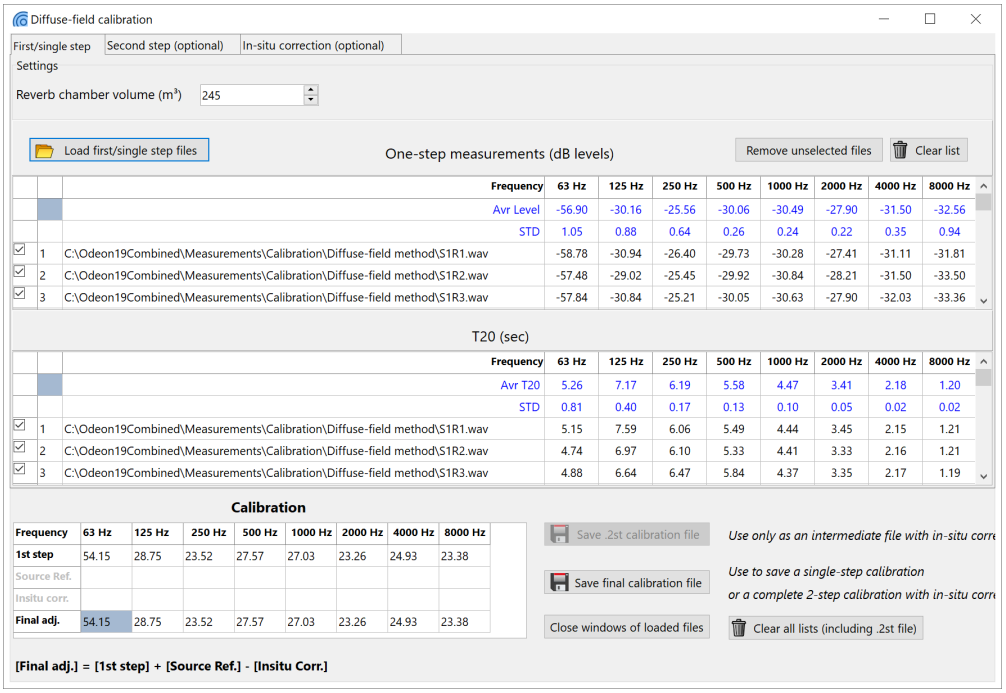
The job list has been equipped with two extra buttons for cloning of jobs with the selected active sources for each individual receiver, or jobs with the selected receiver for each individual source. These tools are useful to create a population of impulse responses in the room with just a few clicks.

Reassign materials by layer

When you modify a CAD model from a software different from SketchUp, and you re-import it into ODEON, this creates a new model, which previously meant having to manually re-assign materials. However, if your CAD model has layers in it, ODEON will now automatically re-assign the corresponding materials to each layer when re-importing.

New calibration interface

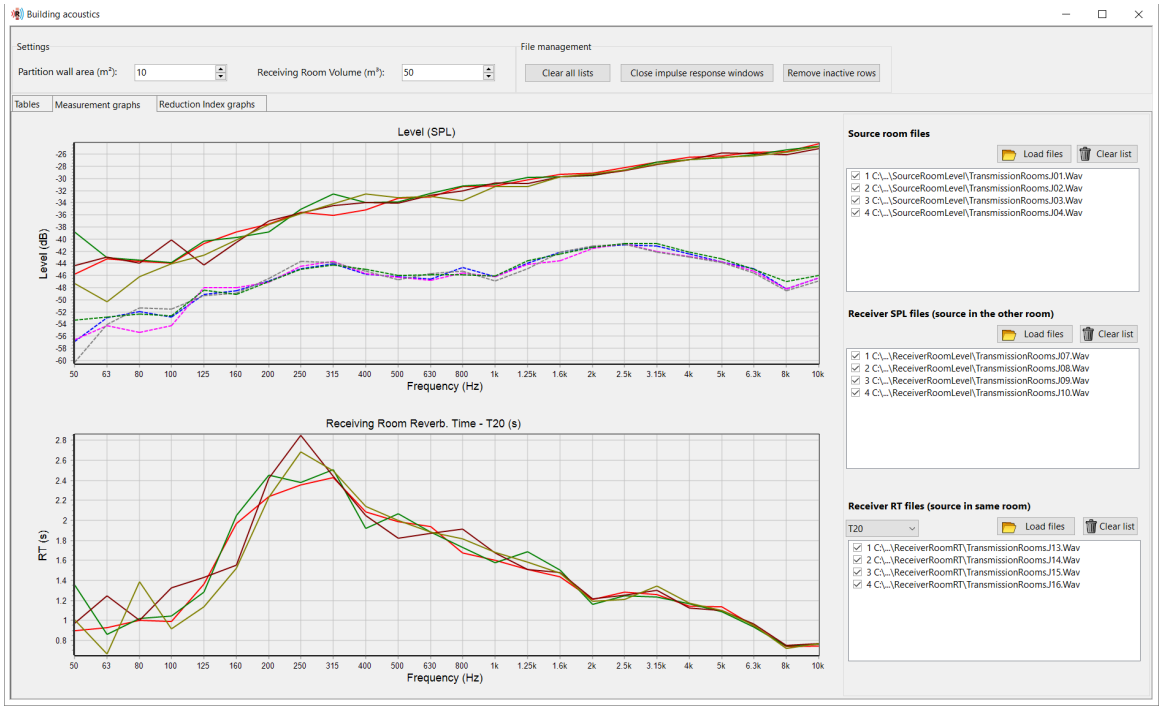
The calibration procedure for G (Sound Strength) and STI (Speech Intelligibility) measurements has been greatly simplified with a new interface. Rather than going through various pop-ups, the full procedure is now done in a single window, where you can add one-step or two-step calibration files in any order, and add extra measurement files at any time.



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Building acoustics module

ODEON 19 includes a Building acoustics module which provides the possibility to calculate the sound insulation properties of a partition wall that separates two rooms, out of measurements carried out in both spaces. The new interface is based on the ISO 10140 standard 'Laboratory measurement of sound insulation of building elements', Parts 2 (ISO 10140-2, 2010) and 4 (ISO 10140-4, 2010).



Open-loop measurements

ODEON can now perform open loop measurements. This means it can generate wave files of sine sweeps, which can be played on an *external device*, while the resulting recordings can be loaded into ODEON to be processed into impulse responses. This eliminates the requirement to emit the sweep and record it at the same time.

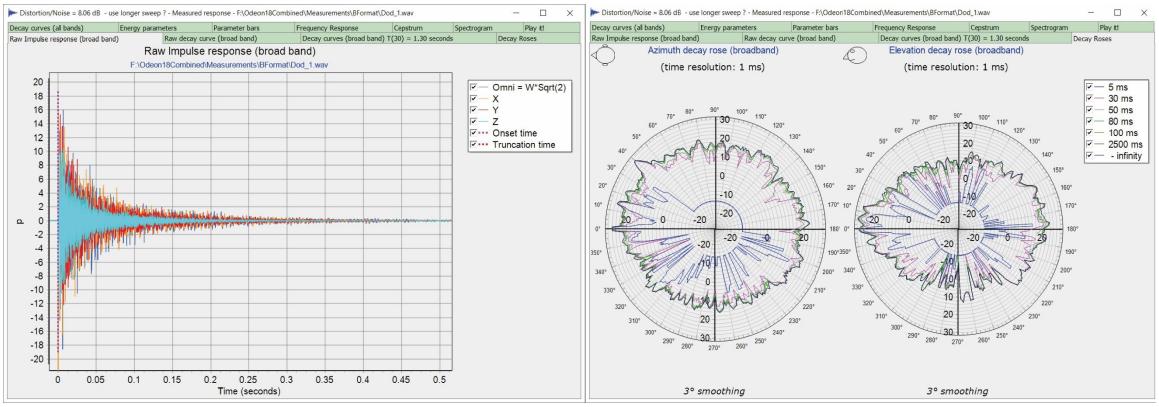
Enhanced ambisonics auralisation

The B-format to binaural algorithm has been revised for measured ambisonics impulse responses. It now follows more closely the calculations made in the 360 auralisation tool. It results in a much better out-of-head experience, and allows you to change the listening direction in real time, while listening to the auralisation.

Decay roses for ambisonics measurements

Decay roses are now added to ambisonic measurements. The interface is similar to the existing decay roses in simulated single point responses.

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Enhancements in Compare and Average tool

The compare and average tool now has a simulated versus measured and targets tab, just like in the multi-point response.

Alternative EDT parameter

ODEON 19 includes an alternative EDT parameter. Currently, the standard way to calculate the parameter is with a linear regression. However, the parameter was originally meant to be calculated without regression. So, the calculation of EDT without a regression will soon be updated in ISO 3382 part 1. This updated way to calculate EDT will already be in ODEON ready for use. Of course, you will still have access to the currently standard EDT.

Links to relevant videos

Links to relevant videos have been added to various pages of the context-sensitive help.

1.4 Features of previous versions

Below we have gathered the most important information of improvements in the previous ODEON versions. Please read more online.

Key features introduced with version 18

Several tools for auralisations were included in this version, namely the *Soundscape App* and the *360 Auralisation* – both available in the Auditorium and Combined editions. The S*oundscape App* is a web application designed to present and compare auralisations outside of ODEON. The 360 Auralisation is a tool embedded in the Job list and allow to listen to binaural auralisations with head rotation.

Another key addition in ODEON 18 was the direct import of BIM geometries (IFC format) into ODEON. Various simplifications are performed during the process, making it possible to import projects from REVIT and ARCHICAD, which can be used for room acoustic simulations. In addition, the *Compare and average multi-point responses* tool, in the Job List, makes it possible to compare two or more multi-point responses (also from different ODEON projects), and it also provides statistics on the room acoustic parameters (both between jobs and between receivers).

ODEON 18 came also with fully re-designed icons in all toolbars, as well as support for high resolution monitors. Read more about all the additions and enhancements.

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Key features introduced with version 17

In ODEON 17, a *Material Calculator* was introduced to design custom materials, such as porous absorbers, resonators and membrane panels. Handling of many sources and receivers was facilitated, especially when creating multi-source auralisations (e.g. the *Source Group Editor*). The measurement facility was completed with temperature and humidity settings and *inverse filtering* for sources and receivers. In addition, various improvements were implemented, including calculation algorithms to handle coupled spaces, clustering of coplanar surfaces and ray loss allowance for outdoor models. The sound power of a source can now be estimated based on the SPL measurements at different receiver positions with the *Source Power Estimation* tool. Furthermore, the release was paired with version 3 of the SU2Odeon SketchUp plugin, which makes it possible to create SketchUp files from Odeon .par files. In addition, loudspeaker geometries can be read from CLF data and displayed in 3D model views. ODEON 17 also introduced customizable interface colours. Read more.

Key features introduced with version 16

Several improvements in the interface of *Reflectograms* and *3D Reflection paths* were made in the single point response results. Among others, reflections can now be coloured with four different colour scales, chosen by the user. Intensity *hedgehog graphs* were added in the *Decay Curve* tabsheet, which allows tracing intensity components in the 3D View. A *3D matrix* tool was implemented, that calculates and displays room acoustics parameters for all combinations between source positions (basically treating one source as the actual source and the rest as the receivers, each time). The measuring facilities were enriched with support for *ambisonic measurements*, *improved auralisation of measurements*, including a *virtual dummy head*, as well as a novel *sweep correction* algorithm that compensates for a potentially poor frequency response of the output device.
In terms of modelling, a new CAD importing interface allows ODEON to read a greater range of formats, such as .dxf, .3ds, .stl, .obj .step, .iges, .ply. files. In terms of source definition, ODEON 16 was able to recognize EASE files directly in the point source editor.
Finally, a *material archive* functionality helps the user to save the 10 most recent versions of the material list, so that any of them can be retrieved, without having to save a new version of the whole room project each time. Read more.

Key features introduced with version 15

In ODEON 15 smooth colour grids made possible, due to an interpolation algorithm that makes grids more presentable, even when large distance between receivers has been used. The feature, together with fully customized colour scales, makes it also possible to construct contour plots (eg. for STI). In addition, the user can now define custom units across ODEON. A set of *Audio effects* was introduced, to help create impressive auralisations of crowds or choruses in rooms. This was accompanied by a *Multi-source/signal auralisations expert*, which facilitates the creation of large auralisation mixes. Finally, the measuring system interface changed completely, with many necessary settings, such as selection of input/output devices and advanced sweep parameters included in the same window.

Key features introduced with version 14

In ODEON 14 an improved 3D Grid interface made it possible to define vertical grids, individual receiver heights for different surfaces and groups of grid surfaces (e.g. floor, 1. balcony, 2. balcony etc.). Parallel processing was applied in more places allowing faster multi source calculations, as well as multi source auralisation. STIPA and MTI parameters were added as well. In addition, a statistical tool for measurements was introduced to display statistics between multiple-loaded

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impulse response files. Regarding auralisation, a user-friendly interface for deriving *inverse filters* for headphones was added. Using this, the actual frequency response of a headphone pair is neutralized (flattened), so that colouration during auralisation becomes minimal. Read more.

Key features introduced with version 13

In ODEON 13 an improved interface was implemented for the Materials list, the Source-receiver list, the Job list, etc. They have all been equipped with sorting functions, better colour display and easier editing properties, such as multi-delete, copy-paste, etc. Another important tool was the *Genetic Material Optimizer*, an extension of the measuring system introduced in version 12. With this tool, the materials in a room model can be automatically adjusted in order to achieve better agreement between simulated parameters in the model and measured parameters in the real room. This makes it possible to "tune" or "calibrate" a model before starting the acoustic refurbishment. Read more.

Key features introduced with version 12

In version 12, simulations and measurements were brought together. A room impulse response measuring system was introduced, allowing the capture of impulse responses supported by a loudspeaker, a microphone and a laptop PC. The tool is available in all editions (from Basics to Combined) and offers easy-to-use simulations and measurements inside the same software package. Moreover, ODEON 12 was equipped with full support for ISO 3382-3 – Open Plan Offices, tools for grouping receivers in the multi-point response, two types of radiation in line and surface sources, calculation of the IACC parameter (Inter Aural Cross Correlation) and many more enhancements. Read more.

Key features introduced with version 11

Parallel processing was introduced with ODEON 11, providing faster calculations on multicore computers. The parallel processing is used for multi-point and grid responses, where many receivers have to be calculated at a time. In addition, a *Fibonacci Spiral* distribution used in ray tracing, allows an optimal distribution of source radiation pattern. A *Room acoustic parameter list* interface allows the user to edit existing parameters and create their own ones. This is a great feature for improving parameters or defining new ones, especially for research purposes. Apart from these, an improved calculation setup, improved grid scaling, echo detection curves, dynamic diffusion curves and many other features were introduced. Read more.

Key features introduced with version 10

ODEON 10 becomes Unicode (and utf-8) enabled, allowing text in complex character sets to be saved with your projects, whether this is in the text files such as the geometry files (.par) or texts composed in the various comment fields in ODEON (the material library is not fully Unicode enabled yet). In particular, Unicode allows text in Asian character sets (Japanese, Chinese and Korean) to be saved from within the ODEON application. It is also possible to save text which is a mix of texts in different character sets. When upgrading to version 10 or later, the order of materials in the Material list has been revised – please see Chapter 4. Read more.

Key features introduced with version 9.1

Starting on version 9.1, ODEON is delivered with a new type of Dongle, which makes it easier for the user to install new upgrades. This is more thoroughly described below in Chapter 1.5 and on ODEON's website.

Version 9.1 has a far better auralisation option than the previous versions for presenting through 2 loudspeakers, called *Super stereo*. With the Super stereo you can make 2 loudspeakers have a much more spacious sound, and with the right frequency response for this type of auralisation.

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Some outdated directivity files such as TlkNorm.so8 have been replaced by TlkNorm_Natural.so8 which is smarter for auralisation use. There might be a risk of adding the overall frequency response twice to auralisation output; once from the directivity pattern and once more from the auralisation signal which inherently includes the same source spectrum (please see Chapter 0 for further information). With the '_Natural' version of the directivity files it is possible to obtain correct equalization of auralisation output while also achieving correct prediction of SPL. Therefore the '_Natural' versions of the directivity files should be used when defining new sources. The old versions of the files are kept in \old_so8\, a subdirectory to the \Dirfiles\ directory. If you wish to use the old directivities in old/existing projects, then open the Source receiver list and click the Repair broken directivity links button (shortcut Ctrl+L).

1.5 How to upgrade or update your current license

For versions 9.1 and later your ODEON software license is stored in a Smart Card based hardware key, the Rockey 6 Smart dongle. As an ODEON user, there are the following update situations. Please contact sales@odeon.dk if interested, to get assistance.

- **Sub version update:** Version number can be updated free of charge in-between the full versions online, e.g. from version 18.1 to version 18.2
- **Full version update:** Your version can be updated to a full version number (E.g. version 18) by requesting a remote licence update. If you have a valid Maintenance and Support agreement when a new version is released, you will automatically receive a remote license update at no additional cost. If you do not have a valid Maintenance and Support agreement, an upgrade can be purchased.
- **Change edition:** It is always possible to upgrade your license to a higher edition if agreed with the sales department. Upgrade from ODEON *Basics* to *Industrial, Auditorium* or *Combined*, or update from ODEON *Industrial* or *Auditorium* to *Combined.*
- **Remove time license:** All **new** licenses are shipped with a time limitation. If your license has a time limitation and the payment has been fully made, this time limitation can be removed by requesting a remote licence update.
- **Update username:** For copy protection purposes, your username and country are embedded in the dongle, but this can be changed. The username can only be updated separately from the other updates.

Your update or upgrade interests could be a combination of the above 4 points, which can be fulfilled by generating a remote request file and following the steps described below. If you have any questions about updates, please send an e-mail to sales@odeon.dk.

Remote License Update or Upgrade is divided into four steps:

1. Generate a license request file and send it to sales@odeon.dk (see below).
2. You will receive a mail with the license file, when your update or upgrade has been generated.
3. Download the received license file to your dongle.
4. Update your ODEON software installation by downloading the relevant version online.

For more info on dongle update, please visit this link.

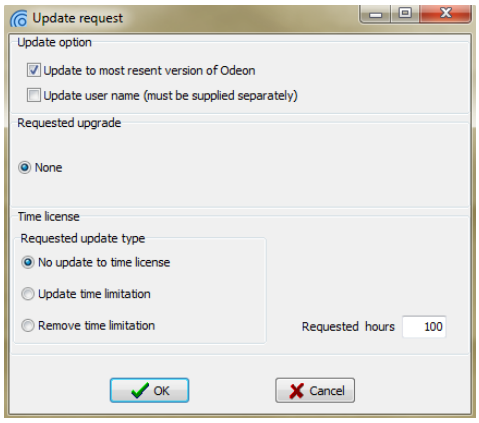
Generating remote request file

A remote request file has the extension .req. To generate a Remote request file follow these steps:

1. Attach your ODEON dongle to the USB port on the PC.
2. Run the ODEON program.
3. Check what your current license includes using the Tools|License information menu entry.

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4. Generate your license request file using the Tools|Generate Remote Update Request file menu entry - this will display the dialog shown below.
5. Email the generated request file (e.g. User2005_Dongle102009.req) to sales@odeon.dk.



Once Odeon A/S has received your request file, an invoice will be processed and sent to you. When the invoice has been paid, an encrypted license file will be e-mailed to you, and this file has to be downloaded into your dongle for the license upgrade (see below).

Updating the dongle – downloading license file (.cif) to dongle

1. Extract the license update file from e-mail to your hard disk e.g. to your desktop.
2. Attach your ODEON dongle to the USB port on the PC.
3. Run the ODEON program.
4. Use the Tools|Download license update to dongle menu entry.
5. Select the file using the Select license update file (.cif) dialog (e.g. select User2005_Dongle102009_ODEON Industrial_VXX__Restricted__RemoteDesktopDisabled_0h.cif).

Update installation

When the update has been downloaded to your dongle, you can find and install the new version or edition on our webpage. You may choose to uninstall the previous version before installation. We recommend that you keep a safety copy of the installation file, e.g. if you at some point want to reinstall the downloaded version.

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2 Modelling Rooms

In order to make simulations of acoustics, ODEON needs a 3D model of the geometry in question. This easiest way to do this is by using a 3rd party modelling software to draw the geometry and then import it to ODEON. You can also change the geometry inside ODEON, but this is mainly for small fixes in the geometry, if the software it originates from is not available for the ODEON user. If you have access to SketchUp, it is possible to make changes in the geometry using the .par file of the room model, even if it was created in a different modelling software. Read more about it in the SU2Odeon manual.

Creating new room models is probably the most time consuming task in room acoustical modelling. However, good modelling practice will surely reduce the time used for modelling and re-modelling rooms.

2.1 Pre-calculated Rooms

Before making any models to be used in ODEON, it is a good idea to have a look at the pre-calculated rooms in your ODEON installation. You will see that a typical acoustic model looks quite simplified – which in principle differs substantially from an architectural model, where all details matter for visual purposes. In an acoustic model, only the most important details should be modelled. In paragraph *What to model* in Chapter 2.2, you can read more about the basic rules you should follow.

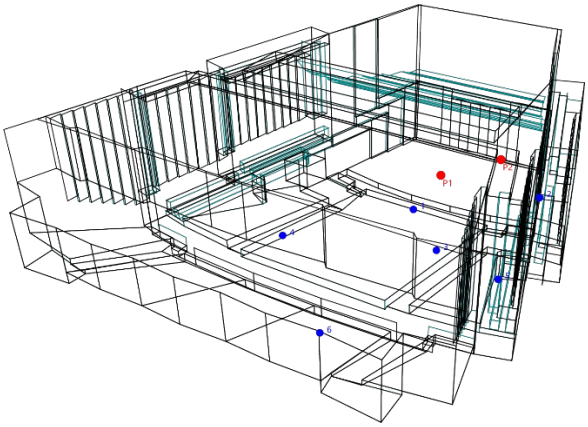
Tip: Find the pre-stored rooms in the Rooms folder in your ODEON installation. The usual path is C:\Odeon15<edition>\Rooms, where <edition> stands for Basics, Industrial, Auditorium or Combined. You can see all relevant paths used by your ODEON installation by choosing Options>Program setup in the top menu bar. More simulations can also be downloaded as a ODEON Zip Archive files in the Examples page on the website.

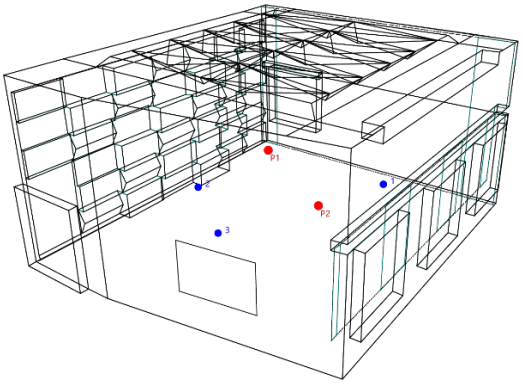
Round Robin rooms

ODEON has been part of the Round Robins, where simulations were compared with measurements for different acoustical prediction software and methods. In the Rooms folder of ODEON, you will find two rooms used as test objects in the 2nd and 3rd Round Robins (Bork, 2000; Bork, 2005). You can check for yourself how the simulation matched the measurements, see how below. The rooms to open in ODEON is Elmia RoundRobin2 detailed.par and PTB_Studio open curtains detailed model.par. The geometry, absorption data, source and receiver positions as well as the measured room acoustical parameters are those supplied to all participants in the Round Robins, by the PTB in Germany.

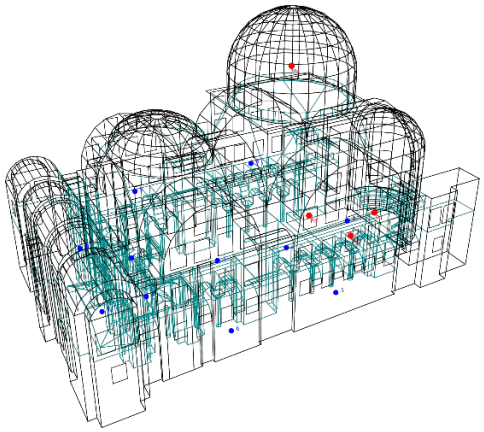
- Open the room in question.
- Open the JobList (Shift+Ctrl+J shortcut).
- Select one of the pre-calculated Multi point response jobs (job one or two) in the JobList and open it (Alt+M shortcut).
- Select the Measured versus simulated tab-sheet in the Multi Point Display.
- To select different parameters in the display, use “Arrow forward” or “Arrow backward”
- To select different octave bands, use “Arrow Up” or “Arrow down”
- To select another receiver, use the R-shortcut or Shift+R-shortcut.

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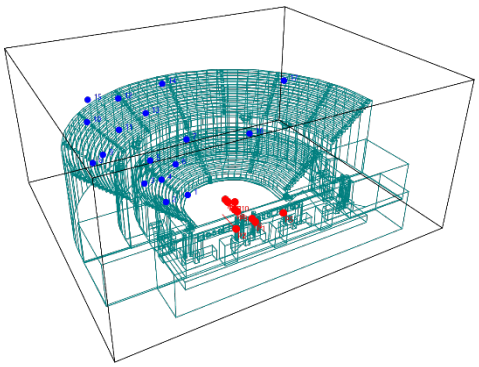


CAHRISMA project rooms



Hagia Irene.par is a model of a Byzantine church in Istanbul. Like the examples above, it also includes measured room acoustical parameters from the actual site. The church was modelled as part of the CAHRISMA project (Conservation of the Acoustical Heritage by the Revival and Identification of the Sinan's Mosques Acoustics). Hagia Irene has an approximate volume of 39.000 m^3 and RT of 4,3 sec at 1000 Hz. You can find similar rooms in the *CAHRISMA project* subfolder. These rooms need to be calculated. Open any of the rooms, access the JobList and press ALT+A to run all jobs.

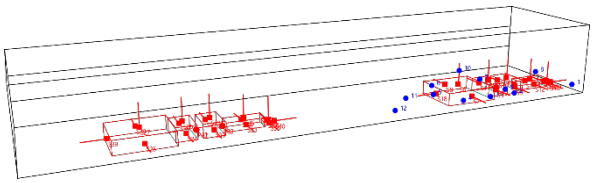
ERATO project rooms

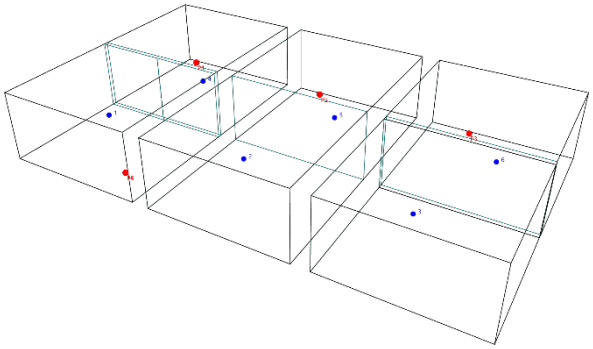


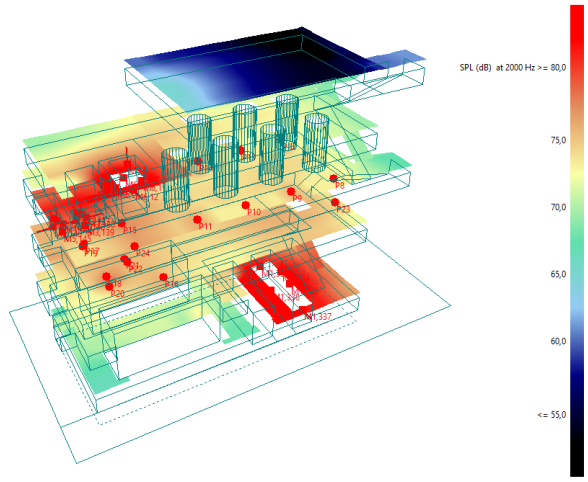
Open the Jerash_Present_Empty.par ancient theatre and observe the bounding box around the room. The bounding box is not part of the actual geometry but it is necessary in such a case where the room is not watertight by itself (there is no ceiling). The box encloses the geometry and allows ODEON to perform calculations. All sides of this dummy box are assigned 100% absorption in order to successfully model the open air. You can find more models from ancient theatres in the *ERATO project* subfolder.

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Noise control rooms







The example Studstrup Power Plant.par, found in the main Rooms folder, is a model of a turbine hall at a power plant. Measured SPL(A) from the actual site is included in this example. Apart from the common point sources, *surface sources* that can model the radiation of sound from surfaces have been used as well. This is due to the assumption that an engine consists of a group of surfaces that radiate sound as they vibrate.

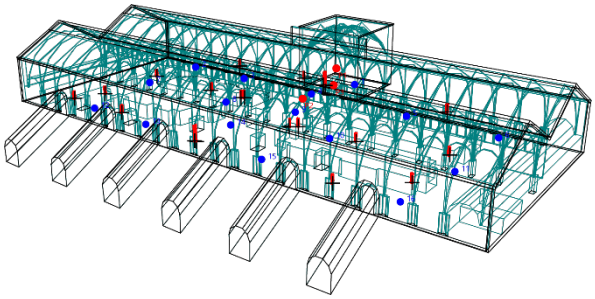
The example Transmission rooms.par, which is also found in the main Rooms folder includes some walls with transmission properties and it serves as a good demonstration of sound insulation between rooms. You can read more about transmission modelling with ODEON in Appendix B.

The room Oil rig.par is an example of an offshore oil platform where loudspeakers have been installed as part of a voice alarm system. Noisy sources have been taken into considerations and they are modelled as surface sources.

This room has also been analysed in the application note *Calculation of Speech Transmission Index in Rooms* which can be downloaded from the application notes page.

Tip: Some of these rooms have been set up for very accurate calculations that can take longer time. If you wish to carry out faster calculations, you may enter the Room setup and select the Engineering setting. This will provide results approximately twice as fast without much loss in quality in results.

Public Address Systems



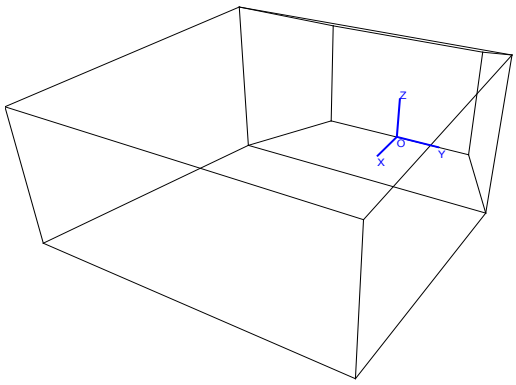
The model Copenhagen Central Station Array.par is available in the Auditorium and Combined editions of ODEON. This example demonstrates a PA system, installed by *Duran Audio*, which utilizes 20 beam steered line arrays. Several measured parameters are available including STI.

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2.2 Guidelines on room modelling

You can choose between importing your rooms from SketchUp, from another CAD program, by typing your rooms directly into a text file, or by using the ODEON Extrusion Modeller. Further below there are some considerations that are common to the different cases, but first some guidelines of general nature are given here.

Default coordinate system



To make it as easy as possible to operate ODEON, the following orientation of room geometries should be applied (using a concert hall as the example):

- X-axis pointing towards the audience.
- Y-axis pointing to the right as seen from the audience.
- Z-axis pointing upwards.

Recommended size of a surface

An important theoretical consideration concerns the size of surfaces in a room model. The classical laws of geometrical acoustics are such that for the purpose of calculating how much energy is reflected; all surfaces are considered to be infinitely large in comparison to the wavelength. For practical room models surfaces are not infinitely large and ODEON is, to some point, able to take into account the limited size of surfaces in calculations – using the *Reflection Based Scattering method* (see Chapter 9.5).

Still, surfaces should be kept reasonably large. Avoid using more surfaces than needed in order to mimic the geometry. Modelling a lot of very small surfaces to achieve high geometrical fidelity will not improve quality of results, but it will increase calculation time. It is difficult to put exact limits on the size of surfaces which should be used; there will always be a need for small surfaces to fill in awkward corners of the geometry.

Remember: A rule of thumb may be to keep surface dimensions larger than one wavelength at the mid-frequencies. One wavelength at 1000 Hz is approximately 0.34 metres.

Often you will be in a situation where a few surfaces should be kept down to 0.20 metres or even 0.10 metres. You can just keep these surfaces if they are relatively few compared to the total number of surfaces.

Tip: It should be possible to model most concert halls with a surface count in between 100 and 2000 surfaces.

Curved surfaces

All surfaces in ODEON must be (almost) planar; so curved surfaces have to be approximated by dividing them into plane sections. But in the ODEON material list, there is a wall type called **fractional** which will make ODEON treat a number of flat surfaces as one curved one. How finely to subdivide the curve depends on the type of curved surface and how important the surface is.

Convex curves naturally disperse sound energy, so if the surface is in an exposed position (e.g. the end of a balcony near the stage), it should be avoided, for example, to replace a quarter circle with a single plane at 45°, as this might instead act like a reflector.

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Concave curves naturally focus sound energy, and since focusing is a fault we wish to model, we must try to arrange this so that it is preserved. However, this does not mean that a large number of subdivisions are the solution. Using many surfaces in the model will:

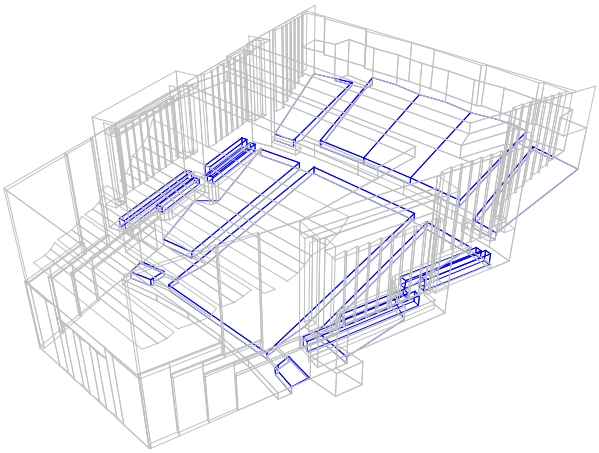
- Make the model visually complex, and increase the probability of errors in the model, typically small leaks may become a problem.
- Not comply with the image source theory used for the early reflections (point sources). See more about calculation principles in Chapter 9.
- Increase the calculation time.

In order to calculate focusing from concave surfaces, it is extra important that the wall type of surfaces forming a concave shape is set to **fractional** in the Materials List. If not, the concave surface will scatter sound too much, taking into account the small areas of the individual surfaces forming the concave shape - rather than the total area of the concave shape. The Reflection based scattering method would produce too much scattering in this case.

Remember: Subdivisions about every 10° to 30° will probably be adequate to reproduce focusing trends of concave surfaces, without excessive number of surfaces, thus walls in a cylindrical room may be modelled with 12 to 36 surfaces. A cylindrical column which disperses energy may probably be modelled with, say, 6 to 8 surfaces.

What to model

Some simple tricks during modelling will save you a lot of time, improve the calculation speed and offer better results, without losing accuracy in the acoustical geometry.



How to model an audience area?

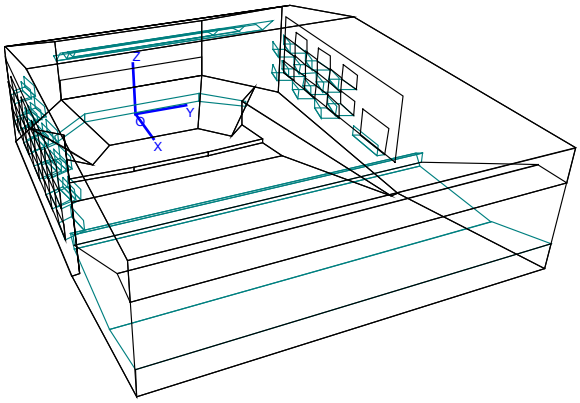
Modelling each step between the rows in an audience area is not recommended. The audience area can be simplified a lot without compromising the quality of the results – in fact, using the suggested method below is likely to produce better results:

- Model the audience areas as 'audience boxes' with a height of approximately 0.8 metres above the audience floor. In the figure above, the audience boxes are indicated by blue colour.
- Assign appropriate 'absorption material' e.g. ODEON material 11001.
- Assign a high scattering coefficient of 0.7 to the surfaces of the 'audience box'. See in Chapter 4 how to assign scattering coefficient on a surface.
- Place the receivers around 0.4 metres above the modelled 'audience box'.

An obsolete alternative solution was to model the audience just as a flat absorptive surface on the floor, mainly for simplifying the model for computational issues. The main problem with this approach was that the absorption area of the room looked smaller, as more rays were likely to hit a hard surface (like the isles between audience areas,) than it would be in real life. In order to compensate for that, the same absorptive material had to be assigned to the isles too. Nowadays, there is no need to follow this approach. By modelling audience as a box this has been proved to be a realistic and reliable assumption, without affecting the computational cost.

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How to model the podium on stage?



The same guideline as for the audience area works here. Rather than modelling each step of the podium on stage, the podium can be simplified into a few sloped surfaces.

Should furniture such as tables, chairs and shelves be included in a model of an office?

If a tabletop is close to a source or receiver point, then it is likely to produce a strong specular reflection towards the receiver, so if this is the case then it should be included. However, the legs of a chair or table should not be modelled in detail. Furniture such as shelves and screens in large office environments, which subdivide the room – breaking up long reflection paths and introducing extra absorption and scattering, should not be omitted. Furniture at more distant locations in the room, which does not produce any strong early reflections to the receiver, can easily be simplified, or even omitted from the model. This as long as the extra absorption and scattering produced by that furniture is somehow included on other surfaces in the same regions of the room.

Orientation of surfaces - does tilt of a surface have any significance on room acoustics?

Small changes to the orientation of surfaces can indeed cause dramatic changes. Making dominant surfaces slightly off-angle can cause extra scattering in the room, almost as if extra scattering had actually been assigned to the surfaces in the room. A typical example is a box-shaped room where a flutter-echo can be removed, by changing the angle of a surface by just a degree or two.

2.3 Files created by ODEON

When importing a geometry, ODEON creates a group of subsequent room files, calculation files and result files. These should normally not be accessed outside ODEON.

All files share the same name - the name of the room - with a different extension added. Three main categories of files are used:

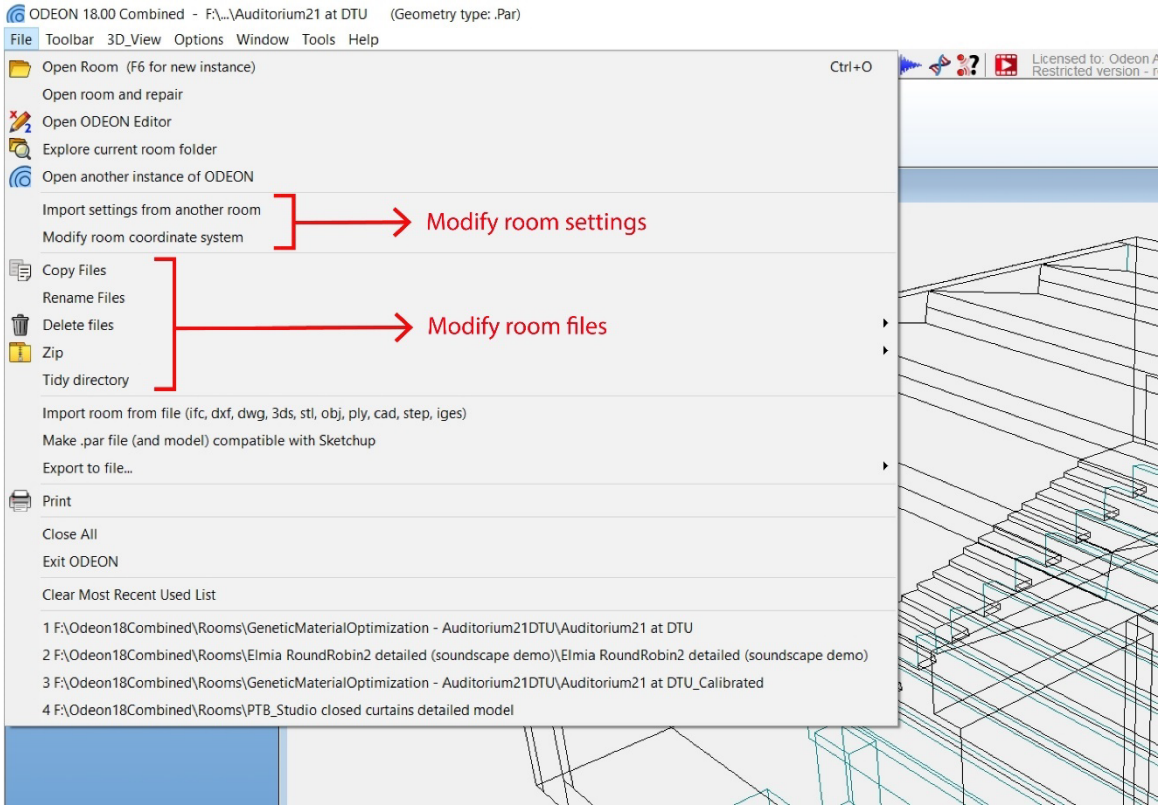
- **Room files**, which contain data entered by the user. From these files both calculation and result files may be re-calculated. Some of the most important extensions are *.par*, which describes the whole geometry, *.PcS* that lists the sources, *.PcR* that lists the receivers and *.Mat* that includes the materials used in the model.
- **Calculation files**, which hold data being re-used during calculations to speed up calculation (of point response calculations). These files can be erased once job calculations have been carried out, however if they are present, future calculations are sped up.
- **Result files**, containing all results. For example, the extension .GNN refers to the grid response results in Job number NN.

See the full list of files in the ODEON help which can be accessed from within ODEON by pressing F1 and searching for *File management*.

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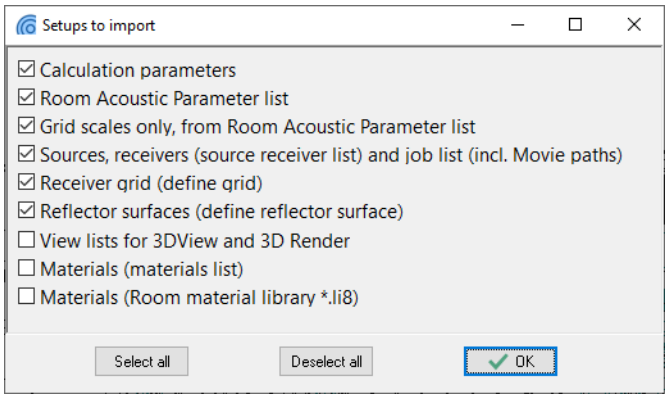
How to handle room files in ODEON

In the File menu on the main toolbar several operations can be performed for a room model that has been loaded into ODEON. In the screenshot below the room operations have been grouped in those who modify various settings in the model and those who help with bulk actions on the files.



Import settings from another room

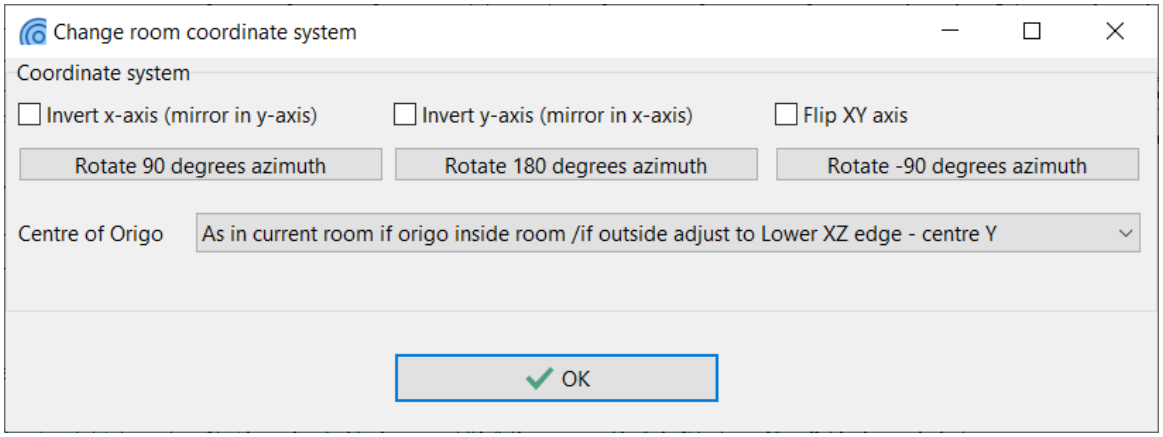
Use this command to modify any aspect of your project with the settings from another room, as shown in the pop-up menu on the right.



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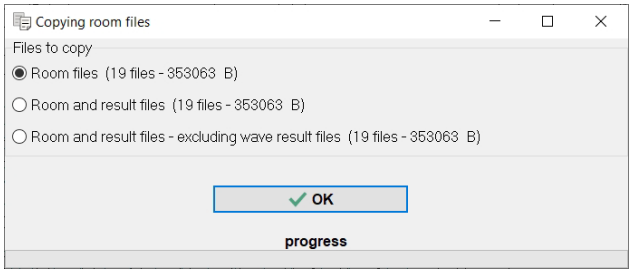
Modify room coordinate system

This is an addition in ODEON 18 and allows to make some specific but common operations in the coordinate system of the model, which eventually change the orientation of the room. You can also change the location of the centre of the origo (the point where the XYZ axes meet). The operation handles changes to the geometry, sources, receivers and grids – keeping data consistent with geometry.



Copy files

The command is used to save a new version of the project you are working on with a different name – similar to the 'Save as' command, found in other programs. You can select to copy the following:



Room files: This keeps all information needed to fully define a project, at minimum disk space. You can then re-run the calculations for the new version later on.

Room and result files: If the calculations would take much time to re-run and space is not an issue on your disk, you can copy both the Room and result files.

Room and result files – excluding wave result files: Similar to the previous option, without any wave files, which can typically consist of large auralisations, which also consume a lot of disk space.

Tip: ODEON does not come with a Save as function, as found in other programs. Instead use the Copy files command which helps you creating a clone of your project and give it a different name.

Rename files

Use the command to consistently change the name of all files associated to a room project, without the need to rename the files manually through the windows explorer. Since every ODEON project consists of many files this is the most secure way to rename a whole project, without missing renaming any files, which could cause your room settings and results to be lost.

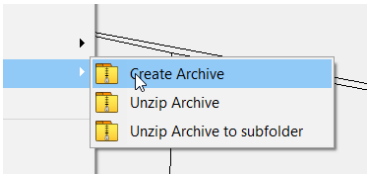
Delete files

The command helps to clean up your folder or to reset the calculations if you anticipate some inconsistency in the results.

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Warning: Be extra cautious for the **All files (remove room completely)** option, because this will delete the full project irreversibly!

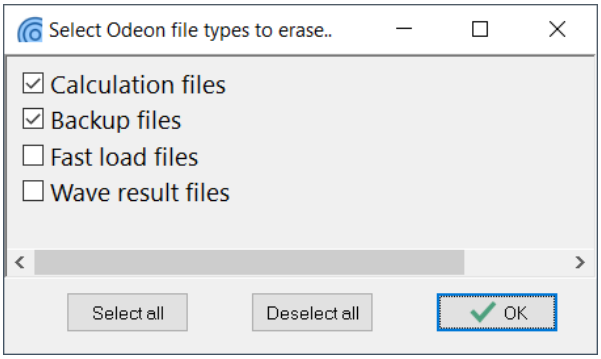
Zip



The best way to share or archive projects is to use the Zip command which makes sure to pack all necessary files within a single Zip file. This is also the recommended way to share a project with the Odeon's team for support. The Create Archive sub-option will ask you to choose if you want to include only the room files or the results as well, similarly to the Copy files option. A file with the extension .OdeonZipArchive will be created.
To open a zip-archived model back in ODEON, use the Unzip Archive sub-option. You can also drag and drop the .OdeonZipArchive file directly into ODEON.

Tidy directory

The command helps you clean your entire rooms folder from various type of files listed in the dialog on the right. It doesn't affect crucial files, such as room and result files, so there is no risk to delete important work done for your projects. Only less important files which consume space on the hard disk can be deleted. Such files are those that help performing new calculations faster or reduce the loading times of the models.



2.4 Importing Geometry into ODEON

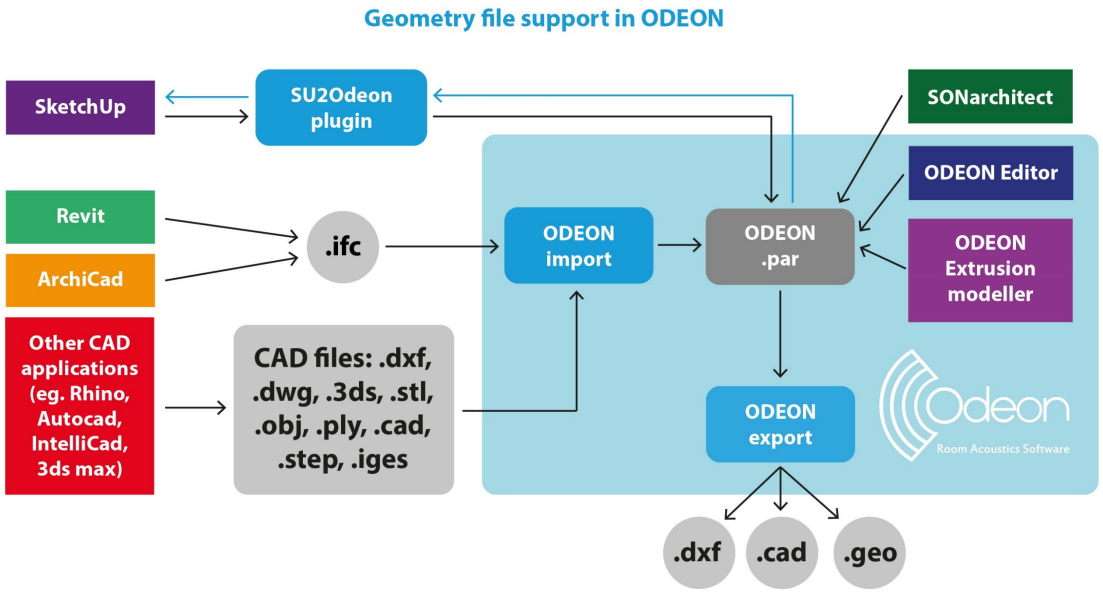
The geometry import format

The file extension used for geometries in ODEON is .par. Most 3D modelling software will be able to export something ODEON can translate into the .par format. Read about importing to ODEON further down. The file containing the room model must be written as a text file (ASCII or UNI-Code), having the file extension.par. The 'old' ODEON .sur file format is also allowed though not described in this manual.

You can choose to create the geometry file by:

- Using **SketchUp** (*recommended*) with the SU2Odeon plugin described in section 2.5. Today this is the fastest and simplest method, used by many ODEON users.
- Using a third-party CAD program (e.g. IntelliCAD, Autodesk Revit, AutoCAD, 3DStudioMax, MicroStation or Rhino) which is capable of creating 3D surface models and saving/exporting these in file formats such as .dwg, .dxf, .3ds, .obj or .stl as described in section 2.6.
- Using Revit or Archicad to create IFC files, which contain meaningful BIM information allowing Odeon to simplify the geometry, as described in section 0.
- Using the ODEON Extrusion Modeller described in section 2.8.
- Typing the model data directly into a text file in the supplied ODEON Text Editor, using the format described in Appendix H.
- Finally, you may combine the different modelling methods; import a CAD model from a CAD program and extend or correct it using tools provided by ODEON.

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Tip: The .par file contains geometry in the Parametric modelling language file format. This format can be edited manually in the ODEON Text Editor (see Appendix H: Modelling rooms in the ODEON Editor).

2.5 Importing a model from SketchUp

Our current most preferred program for room modelling is SketchUp (SU). We offer the SU2Odeon plug-in that allows you to make direct use of SU models in ODEON. SU is a 3D modelling software which is operated very intuitively and creates geometries directly compatible with ODEON and it can be downloaded on the SketchUp website. SU also allows you to create renderings of your rooms for impressive visualization. In order to learn how to use SketchUp, it is a must to watch some of the introduction videos. In a day or less you should have learned the basics. We have also created a few videos on modelling for ODEON with SU which are available on our website.

To make use of the SU models in ODEON, the SU2Odeon plug-in must be installed. The most recent version can be downloaded from the ODEON website. The download includes installation instructions and descriptions of the latest features. Once you have installed SU and the plug-in SU2Odeon, you can start creating models for ODEON using SU.

Save the SU model in the ODEON room folder and press the ODEON icon in SU menu bar. Then SU2ODEON will create a .par file which is saved in the same folder and can be opened directly in ODEON.

Warning: Note that for large models, the SU application may show the message "SketchUp is not responding" while it is in fact still working on creating the .par file - normally it only takes a few seconds but in some extreme cases it might take hours.

The models created in SketchUp and exported by SU2ODEON are inherently compatible with the requirements set by ODEON:

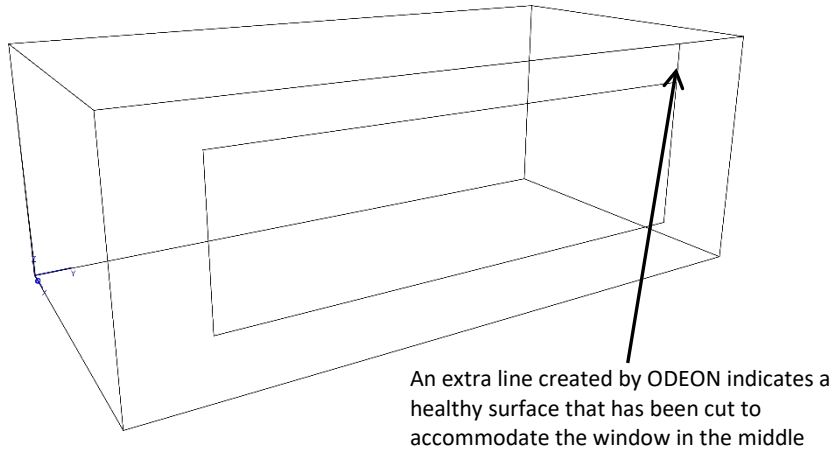
- Plane surfaces.
- No repeated points.
- No surfaces without area.
- Multi loop surfaces are converted into single loop surfaces.

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- Layer support.
- Automatic exploding of groups and components.
- Unique surface numbers.

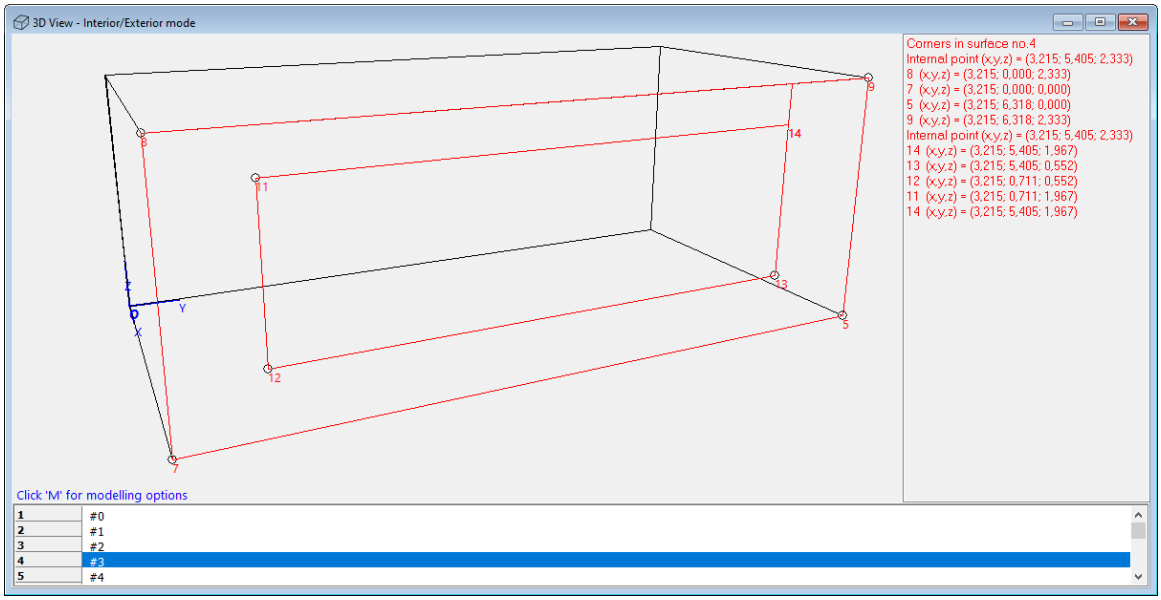
Extra lines appearing in the ODEON model

When one or more surfaces are created inside another surface (e.g. a window on a wall), SketchUp automatically cuts this surface area out of the other surface, so no surface overlap occurs. An extra connecting "line" is created when the model is imported into ODEON (see figure below).



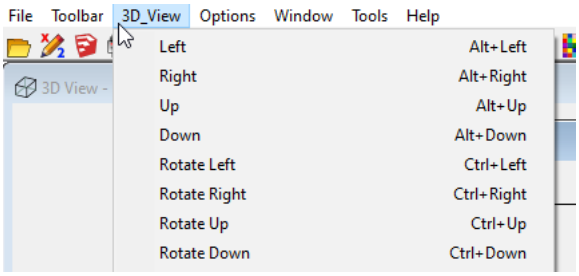
This extra connecting "line" is needed because each surface in ODEON needs to be formed as a series of points in a consistent order (clockwise or counter-clockwise). As a result, when placing a window in the middle of a wall, an extra line appears is created by ODEON to help continuing the series of points. The line is not part of the actual geometry and it is just an indication of a healthy geometry. As can be seen in the next figure, surface No 4 (highlighted by red colour) is created from 9 points.

You can open the display below by opening the 3D View and pressing the N-key shortcut. Select another surface in the list in the bottom of the window using the mouse or using the arrow keys and press the N-shortcut again to view the points in that surface.



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Remember: Always check the context-sensitive menu that appears at the menu bar between the Toolbar and the Options menus. Please do so to view all functions available in the window you are currently working in, and their corresponding shortcuts. On the picture on the right the 3D View window is active and therefore the 3D_View menu appears in the



Remember: Surface properties assigned in ODEON (such as materials, surface sources, reflectors and grid surfaces) are preserved when the model is re-modelled in SU and re-exported for ODEON using the SU2Odeon plug-in.

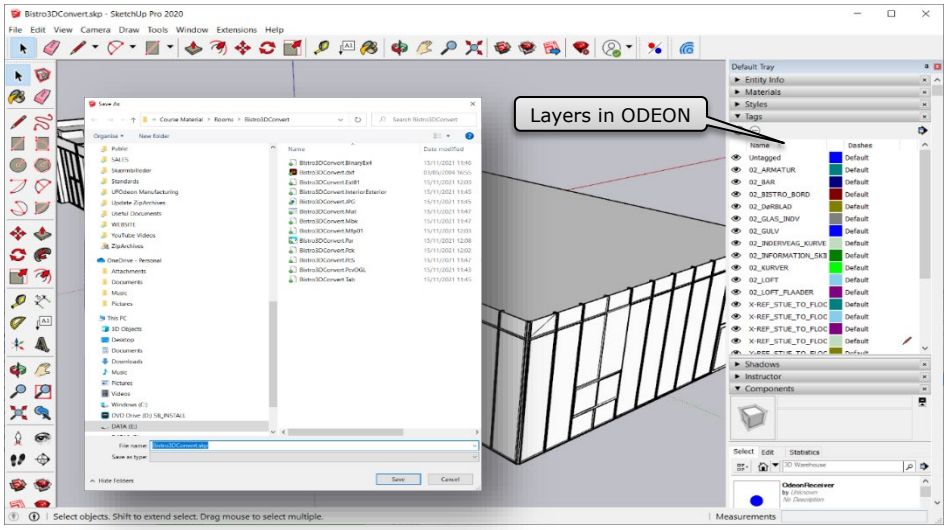
Since ODEON 11, the SketchUp file (.skp file) is automatically copied with an ODEON project when using the File>Copy files menu from within ODEON.

Creating a SketchUp model from the ODEON .par file.

Using ODEON 19 and the SketchUp plugin SU2Odeon version 4 it is possible to import an ODEON .par file into SketchUp and create a SketchUp model from 'scratch'.

- Before any attempt to import the ODEON .par model into SketchUp, it is a good practice to make it compatible with SketchUp by selecting File>Make .par file (and model) compatible with SketchUp.
- Open SketchUp Pro or any other desktop version down to SketchUp 8.
- Click File>import in SketchUp.
- Select Filetype to be Odeon Geometry File (*.Par)
- Select the relevant .par file of the ODEON model and click OK.

The import process starts and might take a while. When it is finished, a 'Save as' dialog pops up. Ideally keep the suggested name, so that any settings you have made so far in the ODEON model (materials, sources, receivers etc.) are kept. On the right side, a list of *Tags* is displayed. These are an exact translation to the layers in the ODEON model.



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The model can now be re-exported/imported into ODEON by pressing the ODEON plugin button on the top-right.

Be aware that during the importing process, some extra surfaces might be created by SketchUp in order to make the model consist of exclusively planar surfaces. This can result in some new surfaces in the ODEON model, without materials assigned to them (no ref.) and changes in the order of layers (and their corresponding colours). In addition, you might experience changes in the surfaces of Grid definitions.

Remember: if you plan to edit an ODEON model in SketchUp at any point, it is a good idea to perform the import from ODEON and re-export into ODEON in the very beginning of the project. Any extra surfaces will be created in SketchUp for the first time and from now on you can proceed with assigning materials, sources and jobs, without risking changes afterwards.

2.6 Importing CAD files

3D CAD programs to use with ODEON

A wide number of CAD file formats can be read directly by Odeon; .dwg, .dxf, .3ds, .stl, .obj, .step (.stp), .iges (.igs) and .ply.

If using AutoCAD or IntelliCAD, the obvious file format is the .dwg format which is the native "AutoCAD" format. Otherwise, the .dxf file format (Drawing eXchange Format), allows import of CAD models exported from modelling programs such as Microstation and Rhino. There are for sure other programs around which can save/export geometry in one of the formats supported by ODEON.

About CAD drawings

The CAD import engine in ODEON supports a number of CAD entities which can be exported from various CAD programs and imported directly by ODEON without any extra effort.
Depending on the modelling program used and indeed how it was used by the user, different approaches may need to be taken into account to ensure that all, or most, of the drawing data is exported to the .dxf file in a form which can be understood by ODEON.

The modelling programs should be true 3D modellers. Programs such as AutoCAD LT only have limited support for 3D modelling and are not recommended. Programs such as Rhinoceros, AutoCAD, IntelliCAD and 3DStudiomax are true 3D modelling programs and have been reported to be suited for the purpose. Other programs may work as well, but in any case, you may have to experiment in order to find the optimum way to export and import the geometries from the programs.

Room models to be used by ODEON must be surface models defined from plane surfaces, regardless if the models are created in a CAD program or if they are modelled in the ODEON environment (e.g. using the ODEON .par format). Once a model has been successfully imported by ODEON, it is important to perform a thorough check – geometries which look fine in the 'drawing program' may still contain serious errors, such as repeated, misplaced or missing surfaces.

AutoCAD entities supported by ODEON

Irrelevant drawing entities which are not supported

Some CAD drawings are in fact 2D "paper drawings" rather than 3D models. Such drawings do not contain sufficient information to create a 3D surface model and are ignored in the import

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process. Examples of drawing entities which may be ignored from an AutoCAD .dwg file are; circles, dimensioning lines, texts, etc. 2D drawing data may coexist peacefully in a drawing containing useful 3D data – as stated, the 2D data is simply ignored.
It is possible to convert a few AutoCAD 2D entities into model data useful for ODEON if handled properly within the CAD program. See the *2½D entities* paragraph.

BLOCK's are supported by ODEON 16 and up

AutoCAD native files (.dxf, .dwg) many times include block entities which are supported since ODEON 16.

2½D AutoCAD entities supported by ODEON: LINE, POLYLINE, CIRCLE

ODEON can import LINE, POLYLINE, ARC and CIRCLE entities, so called 2½D entities, when the elevation height is set to a value different from zero using the ELEV command in the CAD program. Using the ELEV command (at least, this is true in IntelliCAD and AutoCAD) makes it possible to convert parts of a flat line drawing into a 3D drawing – typically a 2D floor plan can be converted into a set of (vertical) walls. Use the CHANGE command in order to change elevation and height of these entities from within the CAD program.

3DPOLY

As an option it is possible to import the AutoCAD 3DPOLY (3D polylines) as if they were surfaces when these lines are closed polygons. When ODEON exports surfaces containing more than four points these surfaces are exported as 3DPOLY-lines. 3DPOLY-lines will not respond to the HIDE or the RENDER commands when imported into e.g. AutoCAD, however it is possible to convert POLYLINE's into REGION entities which are visualized correctly as surfaces in some CAD programs (if the 3DPoly's are not plane, this may not work). In some cases it may be desirable to switch this import option off when importing to ODEON. The DXF file may contain entities which the modeller did not intend to include in the 3D surface model when being imported – the entities may have been modelled for other reasons e.g. as assisting lines in the modelling phase.

POLYLINE (when the POLYLINE is closed and the elevation height is set to zero)

This entity is not really a true surface; however in some cases it is being used by some CAD programs (including AutoCAD) in order to bypass the limitation of the maximum of four points in a surface. If a geometry which was exported from ODEON to the CAD program has to be imported into ODEON again, this option should be on in order to import all 3D data.

3DSOLID, REGION, BODY

These entities are ACIS solid modelling entities, which are directly supported by ODEON, but not older editions. Solid modelling is probably the most powerful way of creating 3D surface models allowing the use of commands such as UNION, SUBTRACT, INTERSECT, SLICE, INTERFERE etc.

Using layers in the CAD drawing

Surfaces will when imported into ODEON include layer information for the layer on which they were drawn. Layers make it easy to assign e.g. material properties to a group of surfaces in one operation rather than one surface at a time. Draw surfaces which should have different materials on different layers e.g. *Stage floor*, *Side walls* etc.

If you are modelling subdivided surfaces such as *Upper wall* and *Lower wall* because you wish to be able to assign different materials to these parts of a surface, it is advisable to model these parts on different layers in order to avoid ODEON gluing (stitching) these surfaces together in the import process (described below).

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Exporting a geometry from ODEON to IntelliCAD or AutoCAD

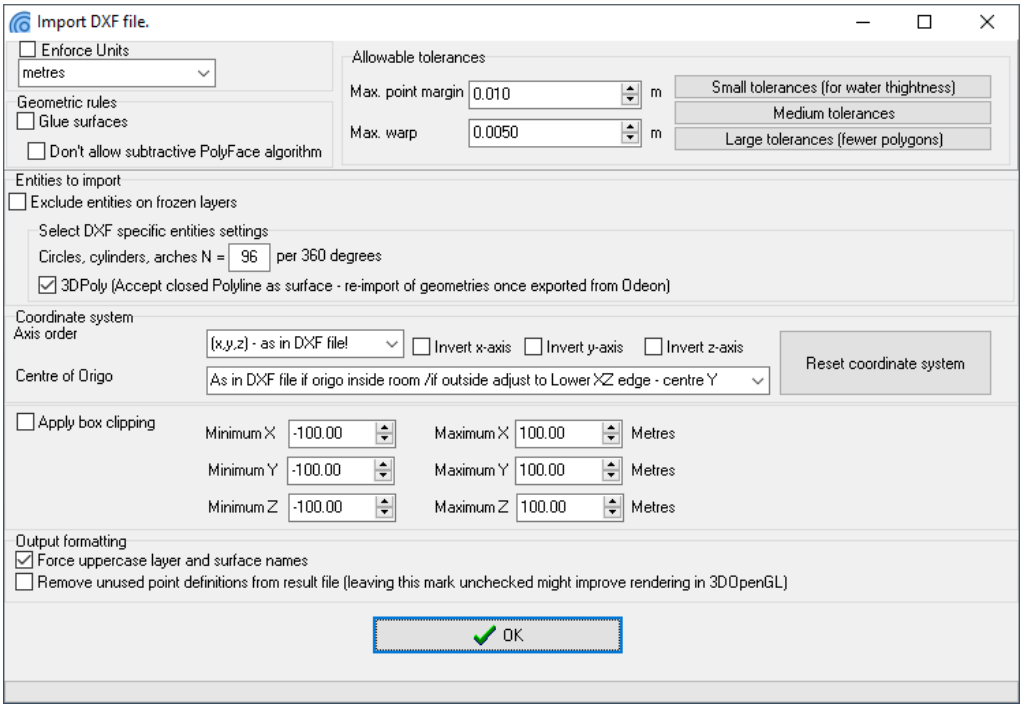
When ODEON exports surfaces containing more than 4 points each, these surfaces are exported using the 3DPOLY entity whereas all other entities are exported using the 3DFACE entity. The 3DPOLY will appear as 3DPOLY lines in the CAD program and does not respond to the HIDE and RENDER commands like entities such as 3DFACE do. However, using the REGION command it is possible to convert 3DPOLY's into REGION's which do respond to the HIDE and RENDER commands.

Performing the import in ODEON

The following steps are generic for the import of any CAD file.

- Select Files>Import from file (dxf, dwg, 3ds, stl, obj, ply, cad, step, iges) or simply drop the file on the Canvas of ODEON.
- Specify the input file e.g. MyCADRoom.dwg.
- Specify the destination file e.g. MyCADRoom.par.

Once the file names have been specified, the Import XXX file (where XXX corresponds to the extension of the input file) dialog appears, allowing miscellaneous import options to be specified. By default, most of the parameters may be left untouched – however it is important that the correct drawing *unit* is specified. If the geometry does not appear as expected, you may try other input parameters.



Unit in input file

Unfortunately, many CAD files are unit-less. It is important that the correct unit in which the geometry was modelled is selected in the import dialog. If the correct unit is not specified the import process may fail because the geometry seems to be only a few millimetres or several kilometres in size.

Geometric rules, glue surfaces

By nature, surfaces imported in the various CAD files are built from three or four sets of coordinates. When the glue option is activated, ODEON will try to glue (or stitch, if you prefer) these surfaces in order to form fewer surfaces with larger areas. Do note that some surfaces (based on poly-faces) may not import correctly *unless* the glue option is activated (and the "don't allow subtractive PolyFace" algorithm is turned OFF).

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ODEON will not combine surfaces with each other when they are situated on different layers in the CAD drawing. If you wish that certain surfaces are not glued together, e.g. if upper and lower part of a wall should be assigned different materials, then draw the surfaces on different layers in the CAD program (preferable) or turn off the glue surface's option (may lead to an excessive number of surfaces and may not work with poly-face surfaces).

Max. point margin

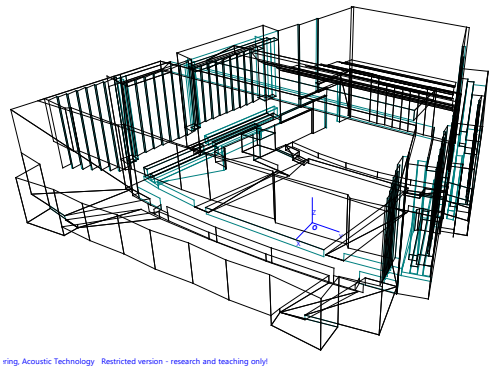
If points in the file to be imported are within this margin, the points will be considered equal. Allowing a certain amount of point margin will allow the Glue function to perform better if the coordinates in the model are not exact. However, if you have modelled both sides of a surface (e.g. outside and inside surface of a balcony front edge) the Max point margin should be smaller than the distance between these surfaces, otherwise the points on either side of the surface will be considered the same, resulting in an undesired outcome.

Max. warp

ODEON will split four point surfaces into 2 three-point surfaces, if the surface's warp exceeds this value. The glue option on the other hand will try to glue surfaces as long as this does not lead to a surface exceeding the Max. warp.

Editing the imported geometry

If it is necessary or at desirable to repair or make changes to geometry after import – this is possible using the 3D View. The 3D View display, which displays the geometry when it has been imported, can be useful tool for this purpose. Please see the context sensitive help available in this display from within ODEON for further details (shortcut F1). Another way to correct a geometry that has been imported into Odeon is by importing the Odeon .par file into SketchUp using the SU2Odeon plug-in, making the desired changes in SketchUp and then reexporting to Odeon – see chapter 2.5.



Exercise: Importing a dxf file and changing its orign

Try importing the file Elmia RoundRobin2 detailed.DXF, which is located in the \rooms\ directory in your ODEON installation.

Tip: In the DXF import dialog, multiple options are available allowing some common changes to the layout of the room coordinate system. The order of axis and/or the direction of axis can be changed. Also some simple changes to the position of the origin can be performed.

Trouble-shooting

Common problems when importing are described below:

Problem with zoom or translation in the 3D View:

Model appears in a strange position on the screen and zoom/translation does not work as expected. This problem is probably caused by some small (invisible and irrelevant) surface(s) located at odd position(s) in the imported model.

Solution 0: If you have access to the CAD software in which the model was created, make changes in this software and save/export the file again.

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Solution 1: Try importing the geometry once again with some of the entities unchecked (turned off), it may be that some of the entities, such as 3DPOLY or the like were not intended to be surfaces in the surface geometry.
Solution 2: Removing the unwanted surface:

- In the 3D View turn on the 'Modelling options' (M-shortcut), look out for odd positioned points.
- Move the mouse cursor to the position of the odd point - read one of these point numbers
- Click the ODEON Editor icon to open the .par file, remove the point and try to reload the room by clicking the ODEON icon in the Editor. Now ODEON will hopefully report an error stating a surface is referencing the point (which no longer exists)
- Remove that surface along with ALL the points it is referencing (out-comment them)
- Reload the room.

Problem with display of coordinate system: The blue coordinate system looks odd or behaves strangely.
Solution: If the *Orign* is situated in a point far away from the geometry, the coordinate system may not display properly when projection is turned on – in that case turn off the projection using the P-shortcut. In order to fully solve the problem, the position of the orign should be altered by reimporting the geometry and e.g. selecting Centre of origo to be Lower XZ edge - centre Y in the import dialog.

The geometry displayed in the 3D View appears to be too small or large after re-import:
If the geometry was initially imported using an incorrect unit, then ODEON has defined its default view list in the 3D View in order to display the initial version of the geometry correctly. To reset the view list, use the Ctrl+DEL Shortcut from within the 3D View.

2.7 Importing files with BIM information into ODEON

Building Information Modeling (BIM) is a digital representation of construction projects that can include various aspects of a building project, both physical and functional. A particular feature is that different elements of a building are classified in categories, which can include extensive information, such as geometry, materials, schedules, quantities, etc. The IFC (Industry Foundation Classes) format was developed and standardized in order to facilitate the export of a BIM project (or part of it) to other software. It is an open format, which can contain BIM information. A common practice is to export only a subset of the BIM data to the IFC file, depending on its application. This is called Model View Definition (MVD). For instance, electrical installations or pipes are unnecessary for acoustic models, so they can be excluded from the IFC file if it is meant to be used for acoustic simulations.
Due to their versatility, BIM projects have become more and more common in the architectural world. However, they contain a lot of data that is completely irrelevant for room acoustic simulations. Geometries also tend to be way too detailed to be properly handled in ODEON. For instance, a window can be made of hundreds of surfaces in a BIM model, but a simple rectangle may be sufficient for an ODEON acoustic simulation, according to the guidelines about minimum sizes discussed in Section 2.2.
Since Version 18, ODEON can import BIM models. The general principle is to select the relevant components and geometries in the BIM model, to produce an ODEON-compatible file, and to apply simplification algorithms to the geometry. The BIM information can be used for treating different elements of the model in a specific way. This section presents how to produce files with BIM information that are compatible with ODEON, and how to import them.

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Requirements

BIM software

- Currently, ODEON supports BIM files exported from **Revit** and **Archicad**. The initial models should be native Revit or Archicad files.
- The BIM elements supported by Odeon are walls, floors, ceilings, roofs, windows, curtain panels, doors, columns, stairs, ramps and furniture. These are considered to be the building blocks for a room acoustic model.

Note: IFC files created with Revit are better suited for an ODEON import than files created with Archicad. Therefore, we primarily recommend the use of Revit.

Supported file formats

ODEON supports **IFC**, **DXF** and **DWG** files, which are all well-known exchange formats.

IFC support

IFC files are an open format which can be exported by BIM software. The different components of the BIM model belong to so-called IFC classes, depending on their nature. The list of IFC classes is standardized, but ODEON will focus on the ones that are relevant to acoustic modelling.

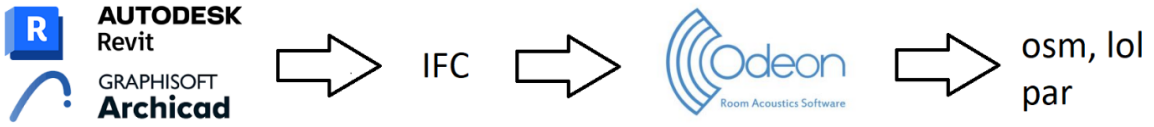
DXF/DWG support

DXF and DWG files are two popular exchange formats for CAD models. Importing such formats was already possible in previous versions of ODEON (see Section 2.6), but DXF and DWG files can also contain BIM information if exported by Revit. Therefore, ODEON 18 treats DXF and DWG files exported from Revit differently in order to optimize the import.

Note: importing IFC files is much faster in ODEON, so we recommend this format. To learn more about importing DXF/DWG files with BIM information in ODEON, please read Appendix I.

General workflow

As the import of IFC files is faster and more robust, we focus on this file format. The figure below summarizes the workflow when importing a BIM model into ODEON.



The first step is to create an **ODEON-compatible IFC file** from a BIM program (Revit or Archicad). In the context of acoustic modelling with ODEON, the output IFC file should have a simplified geometry, and relevant BIM information should be included (all exported elements are assigned an IFC class).

When importing compatible IFC files, ODEON creates **intermediary files (OSM, LOL)**. The OSM (ODEON Surface Model) file contains raw geometric data. The LOL (List Of Layers) file contains the layers to import into the ODEON model. Typically, there will be one ODEON layer per type of BIM element (e.g., door, furniture, ceiling). The generation of these intermediary files may take some time, especially for heavier models. However, they make ODEON reimports faster, as the geometry no longer needs to be read from the IFC file. This can be useful if you want to import the

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model again with different settings (e.g., units, gluing, tolerances) or if you wish to include only a selection of layers in the ODEON model.

Tip: if the import of an already existing IFC file does not work, it can be a good idea to delete the OSM and LOL files, and restart the import from scratch.

Using the intermediary files and a set of user-defined import parameters, an **ODEON geometrical model (PAR file)** is created. Some elements of the geometry are simplified in the PAR file in order to optimize the model for room acoustic modelling. Note that once a model was imported into ODEON, it is also possible to modify its geometry directly in SketchUp, by making it SU compatible and importing the PAR file into SketchUp.

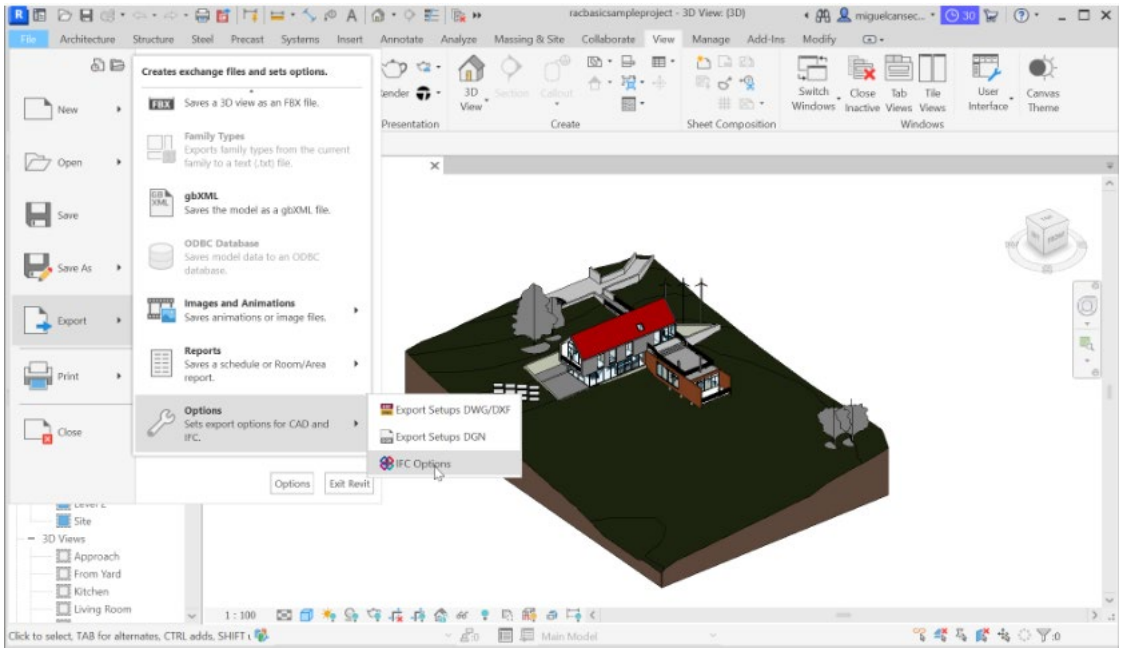
Creating ODEON-compatible IFC files

With ODEON 19, IFC files should exclusively be created with Revit or Archicad. With both programs, you should first map the elements of the model to a series of relevant IFC classes to be exported. Then, a manual clean-up of the model is recommended to restrict the exported geometry even more.

IFC files with Revit

ODEON export layer file

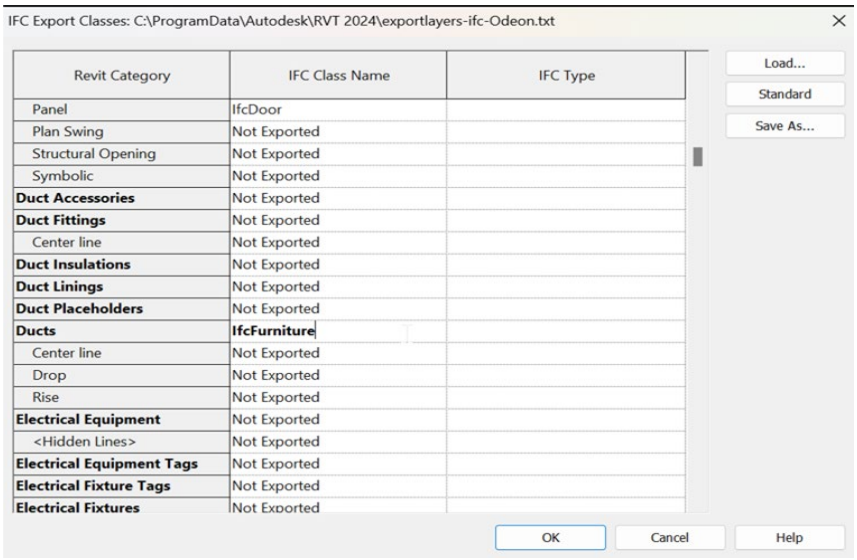
In Revit, the elements of the model belong to categories and/or subcategories, which are an integral part of the software. These categories should first be mapped to specific IFC classes. This is done by loading the text file exportLayers-ifc-Odeon.txt, which is available in C:\ProgramData\Odeon\CAD_Support. This folder can also be accessed from ODEON, by clicking on Options/Explore CAD Support files. In Revit, go to File/Export/Options/IFC Options, click on Load and search for the file.



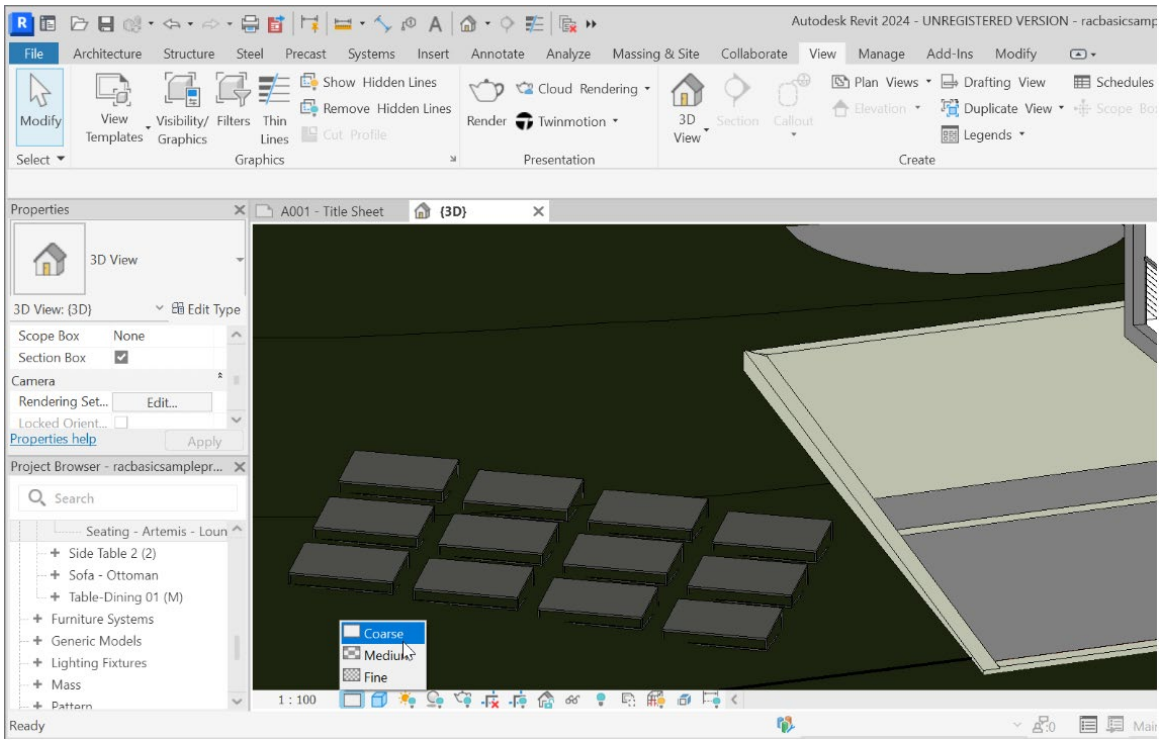
This procedure restricts the data that is exported to the IFC file, as many Revit categories have nothing to do with the geometry of interest for room acoustics modelling (2D drawings, scales, text labels, legends, etc.). Many non-architectural elements are also excluded on purpose (pipes, cables, lightening, appliances, etc.).

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The selected subset of IFC classes should be enough to describe a model for room acoustics analysis. This includes IFC Classes regarding walls, floors, ceilings, roofs, windows, curtain panels, doors, columns, stairs, ramps and furniture.
If you want to export a particular category or subcategory that is not included with the ODEON export file, you can map it to the **IfcFurniture** class. For instance, if you want to export Ducts:



Prepare 3D view in Revit
With the mapping described in the previous section, most of the unwanted geometry will not be included from the IFC file, and you will be able to import your model into ODEON. Nevertheless, it is recommended to clear the geometry even further by hiding unnecessary elements in the 3D View of Revit. The 3D View is accessed via the View tab, as shown in the screenshot below. This process will result in a lighter IFC file and a cleaner geometric model.
In terms of model precision, it is recommended to select the coarser level of detail representations for the elements of the model, as a fine resolution is not desired for acoustic simulations.



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Modify the IFC export setup

Before exporting the model, a few settings should be made in the IFC export setup. With your 3D view still open, select File/Export/IFC to open the IFC export window, and then click the Modify setup button. In the Modify Setup window, select the following options:

- **General:** the recommended IFC Version is **IFC 2x3 Coordination View 2.0**. Other IFC versions might work but this is not guaranteed.
- **Additional content:** check Export only elements visible in view. This option is needed if you manually hid parts of the model geometry.
- **Property sets:** check export IFC common property sets.
- **Level of detail:** select the coarser level of detail available (Extra Low).
- **Advanced:** nothing checked.
- **Geographic Reference:** Coordinate Base should be Internal Origin.

IFC files with Archicad

Mapping with an IFC translator

The mapping from Archicad elements to IFC Classes is controlled by a translator. The **DDS-CAD translator**, provided by Archicad, is recommended to export the IFC files. ODEON will make use of this mapping to import only the relevant classes (i.e., those concerning walls, floors, ceilings, roofs, windows, curtain panels, doors, columns, stairs, ramps and furniture).
A difference with the export with Revit is that many non-supported categories are also exported with the DDS-CAD translator. It is during the ODEON import that the spurious elements are discarded. This is not a serious issue, but the resulting IFC file will be larger and will take longer to read than with an export from Revit.

Cleaning the model

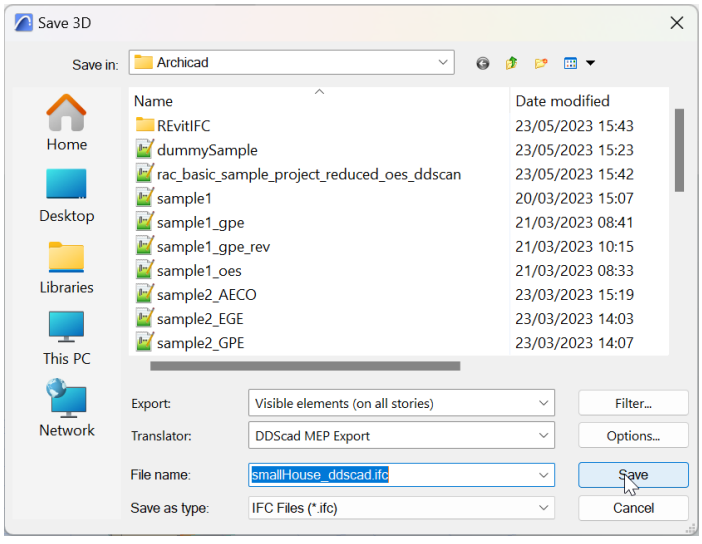
When creating your own model with Archicad, remember to favor architectural tools for the modeling (avoid railing and beam tools). If the model was made by someone else, you can hide the elements to be excluded in the export, such as those belonging to IFC classes not supported – in the same manner as with Revit.

Make the export

In order to export the model, go to File>Save as.

Select the following options:

- **Export:** Visible elements
- **Translator:** DDScad MEP Export
- **Save as type:** IFC Files (*.ifc).



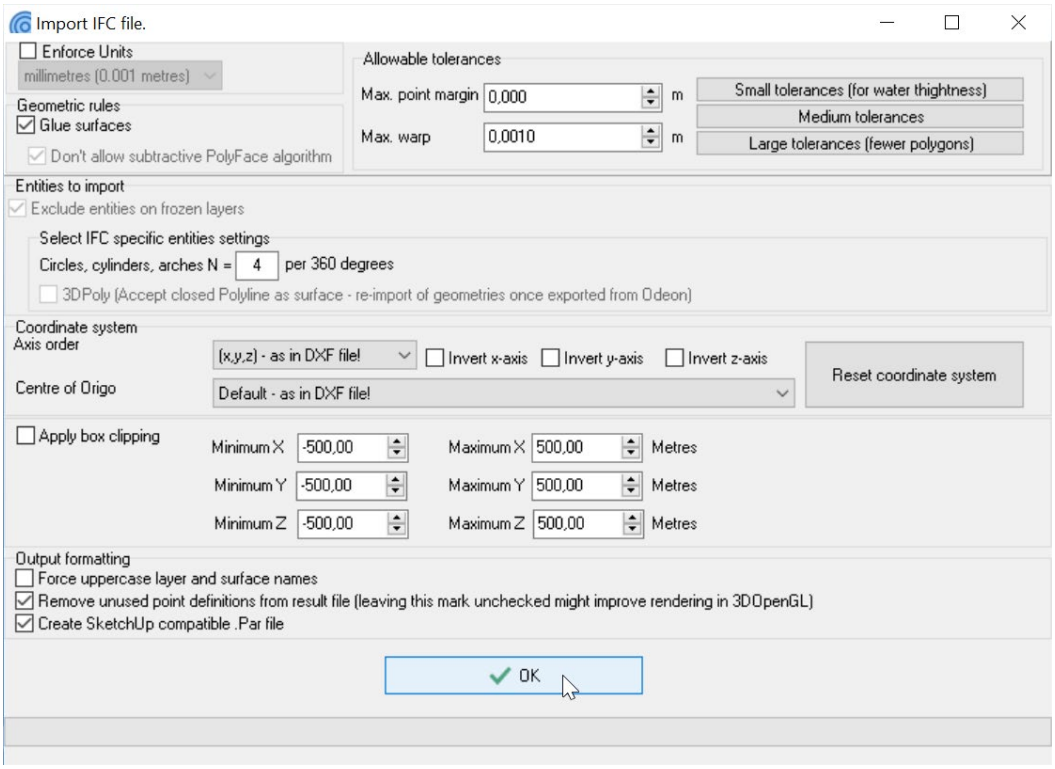
Tip: once the IFC file has been created, it is good practice to check the content of the IFC file itself, especially its geometry. Many free IFC viewers can be found online (e.g., Autodesk Viewer).

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Importing compatible IFC files into ODEON

Once a proper IFC file has been created (either with Revit or Archicad), it can be imported into ODEON. Simply drag and drop the IFC file onto the ODEON canvas to start the import procedure. You can also click on File>Import room from file. ODEON makes use of the BIM information in the IFC file to classify the geometry into different element types (walls, floors, ceilings, roofs, windows, curtain panels, doors, columns, stairs, ramps and furniture). The building elements are grouped into ODEON layers according to their nature.

Once the IFC file is read, and the intermediary OSM and LOL files are created, you can choose the name and location of the resulting PAR file in a Save dialog window. Then, the IFC import settings window will open. The settings are overall similar to those for importing CAD models (see Section 2.6).



Units

The units are generally written in the IFC file. We recommend to leave Enforce Units unchecked; they will be read during the import and converted to meters in the PAR file.

Simplification

Elements of different types are processed differently. For example, columns are examined by a circular column detector, and they are replaced by a prismatic column with as many lateral faces as the input parameter **N**, specified in the Import IFC settings. Windows and doors are collapsed and projected to the center-planes of their container walls, becoming a single surface. Curtain panels and their mullions are collapsed and united together for further simplification. This simplification alone will reduce the number of surfaces dramatically in the final PAR file (compared with the original version).

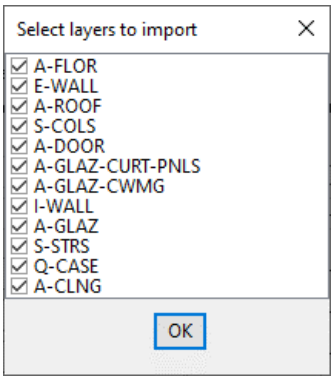
Gluing

The gluing technique is applied separately to BIM elements that have not been collapsed. The processing is therefore faster than for traditional CAD models.

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Tolerances

The **Small tolerances** preset for Max. Point Margin and Max. Warp parameters is recommended for the import of IFC files. Increasing these parameters will not reduce the number of surfaces much more, but it will impact the accuracy of the model.



After having selected your import settings, press OK. The last step is to choose which layers to import into ODEON. Each layer corresponds to a building type, read more in the next subsection.

To validate your selection, click OK and the import will start.

Layers in an ODEON model from IFC

The layers in an ODEON model imported from IFC reflect the building element types in the model. Below is a summary of the most common layers.

E-WALL	Exterior walls
I-WALL	Interior walls
A-WALL	Unspecified walls (not common)
A-DOOR	Doors
A-GLAZ	Windows
A-FLOR	Floors
A-ROOF	Roofs
A-CLNG	Ceilings
S-COLS	Columns
S-STRS	Stairs
Q-CASE	Furniture
A-GLAZ-CURT-PNLS	Curtain panels
A-GLAZ-CWMG	Curtain panel mullions

Floor and ceiling detection

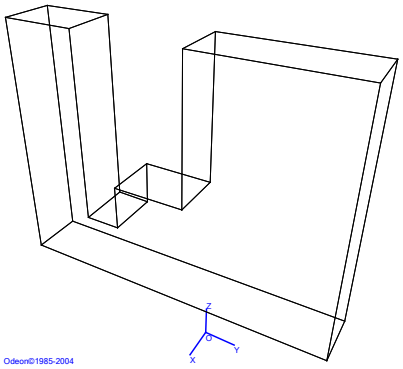
One of the specific treatments of BIM models is the detection of top surfaces in floor elements. These surfaces are normally the only ones exposed for ray tracing, and they will be moved to a special layer called A-FLOR-CLNG. If that is the case, the rest of the A-FLOR layer can be ignored for acoustic simulations, and it can be assigned **Material 0 "Transparent"**.

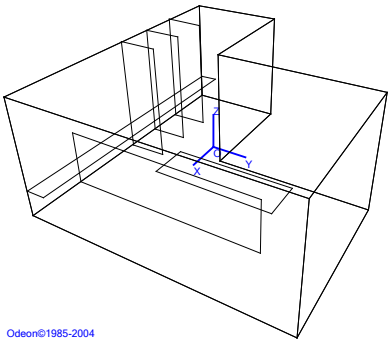
Similarly, the surfaces that form the bottom lid of ceilings and roof elements are moved to the layers A-CLNG-FLOR and A-ROOF-FLOR, respectively.

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2.8 The ODEON Extrusion Modeller

A small modelling program; the ODEON Extrusion Modeller is included with ODEON. The program is found in the Windows start menu along with the ODEON program. It can also be launched from within the ODEON editor.

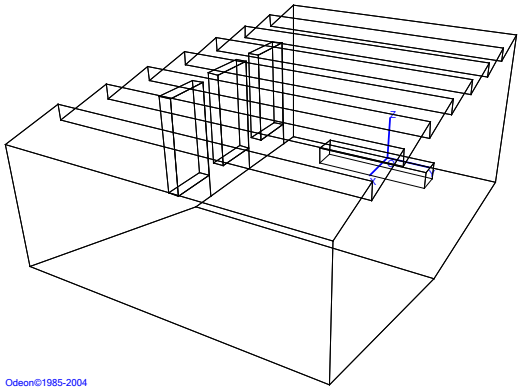




The Extrusion modeller allows to model "extruded geometries" in a graphical environment, or in other words, to draw geometries using the mouse. An extruded surface is a flat 2D outline, drawn at a specified drawing depth (the third coordinate) and with an extrusion height. When assigning an extrusion height to the 2D outline, it becomes a holster outlined by the edges of the 'extrusion surface', if desired this holster can have a bottom and a top.

In the extrusion modeller, it is possible to make one drawing which contains multiple extrusion surfaces, each described by a 2D outline (a simple drawing) and the line properties; drawing depth, extrusion height, bottom check mark, top check mark and a name. If the extrusion is created in the XY- plane (the ground), then an extrusion surface may form a volume with walls and optional floor and ceiling, whereas other extrusion surfaces define tables, chairs or screens.

For some geometry it may be more appropriate to draw the room in one of the other main planes (XZ and YZ planes). As an example the auditorium.par model in the figure to the right has been modelled in the XZ plane (starting from a wall), using separate extrusion surfaces for the room, the wall with windows holes, the table and the windows.



The Extrusion Modeller and file formats

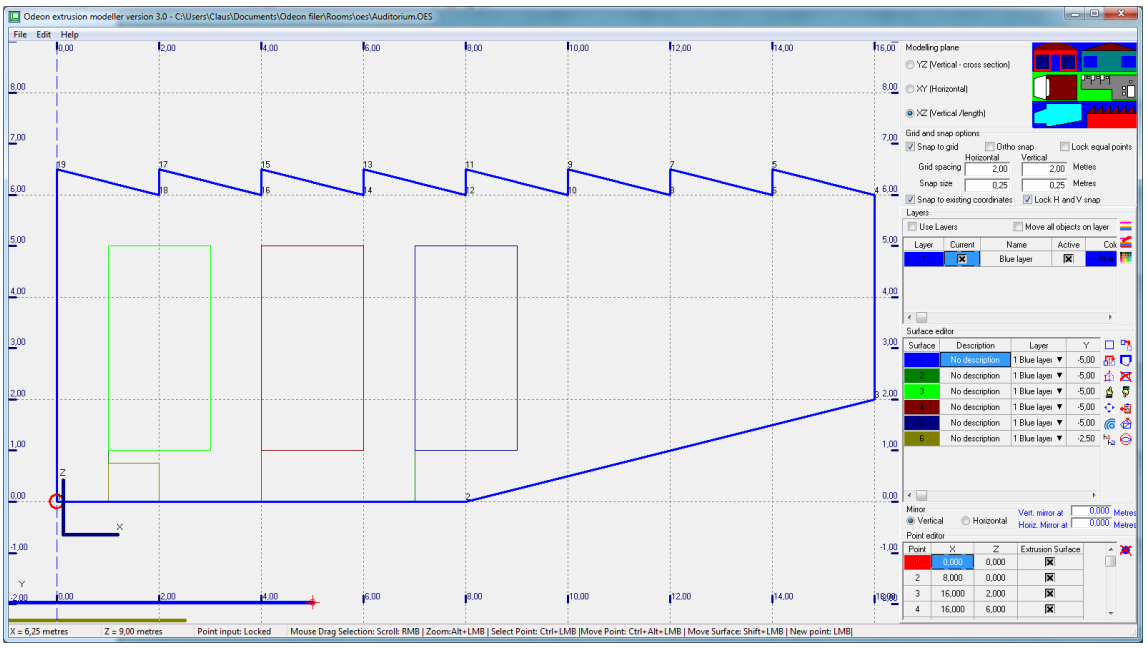
The output from the extrusion modeller comes in two formats. The first is its own native format, an .oes file, where the extrusion model is saved. This file can be edited and extended at a later point in the extrusion modeller e.g. if wishing to change width of the auditorium above, to change some of the points in the drawing or to add other features.

The other format is the ODEON .par format which is loaded into ODEON for calculations. The parametric format cannot be edited in the extrusion modeller; on the other hand it may be manually edited to any degree of freedom if needed and it is possible to make use of the benefits of the parametric format described in Appendix H: Modelling rooms in the ODEON Editor, e.g. when modelling geometric shapes such as cylinders and domes, when combining 2 extrusions in different planes, or when it is appropriate to describe parts of a geometry using parameters. The .par file can be edited in the ODEON Text Editor. The 3D View available in ODEON is a useful tool when investigating or modifying an already existing file; load the .par file into ODEON, study the room in the 3D View – please see the help text (shortcut F1) available from within this display, then make the changes in the editor which can be opened from within ODEON.

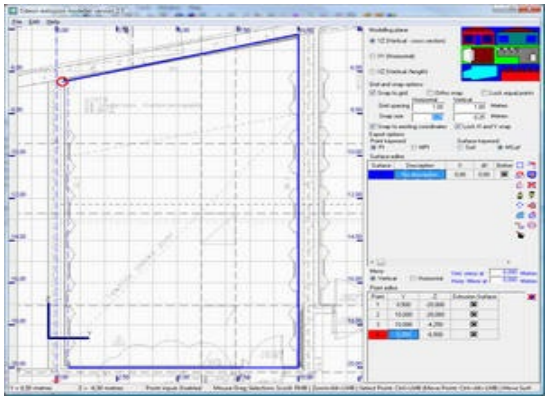
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Using the Extrusion modeler

Start the program; a shortcut to the program is found at the Windows Start Menu Start|Programs|ODEON|ODEON Extrusion Modeller.



Initial settings



Before starting to model geometry, select the drawing plane (XY, YZ or XZ) which is best suited for the geometry to be modelled. Also select properties for grid and snap spacing.

Using a drawing of the floor plan as the layout

It is possible to load a 2D background drawing section plan as basis for the geometry in various image formats (png, jpg, gif, emf, wmf,) and to use this drawing as the basis for the drawing.

To load a background drawing

- Use the File|Load backgound drawing menu to locate your image file.
- Double click on your desired orign in the drawing as requested (could coincide with an intersection between a horizontal and a vertical module line).
- Double click at a point having some horizontal distance from the orign as requested (could be another vertical module line).
- Enter the distance between the two points (e.g. distance between vertical module lines).
- If the drawing is very dark, this may be disturbing, use the File|Make background drawing lighter to lighten the drawing. (This can be repeated).

The drawing has now been scaled and is fixed to the drawing canvas - when scrolling the drawing canvas or zooming, the drawing will adjust appropriately. If not satisfied with your scaling of the drawing, repeat the process above.

Drawing an extrusion surface

Left click the mouse at the positions where the points in the surface are desired – if no points and lines are generated, then you need to bring the current surface in edit mode using the Insert (or Esc)

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shortcut or by double clicking a point in the surface. Once all points in the surface have been defined, finish the current extrusion surface by starting a new one, using the Ctrl+A shortcut or pressing the Insert or Esc shortcut. To assign a drawing depth (X,Y or Z) and an extrusion (dX, dY or dZ), select the surface in the Surface editor table where it can also be specified whether the extrusion surface should have a bottom and a top and where a Description may be entered. The drawing depth and extrusion for each extrusion surface is displayed graphically at the bottom of the application window.

Editing or correcting an extrusion surface

In order to make corrections to an extrusion surface, select it in the Surface editor table or click one of its points in the drawing area, then bring it into edit mode using the Insert (or Esc) shortcut. Once in edit mode, it is possible to change coordinates of the points, insert or delete points, and to move the surface using the mouse operations listed below. It is also possible to enter the precise coordinates of points in the Point editor table which list the points in the selected surface, so it is an option to draw a sketch using the mouse and then fine tune the coordinates afterwards in the Point editor table.

Operation on surface	Mouse operation
Create a new point in selected surface	LeftClick mouse
Select the point in selected surface, which is closest to Mouse pointer	Ctrl+LeftClick mouse
Move closest point in selected surface	Ctrl+Alt+LeftClick mouse
Move selected surface	Shift+LeftClick mouse

Manipulating the viewport

The viewport can be manipulated using the shortcuts listed below. It is possible to make changes to the view while drawing a surface.

View operation	Mouse operation
Scroll drawing area	Right mouse button
Zoom (In/Out)	Alt + Left mouse button

Snap to grid

Snap to grid enables points (new points or points being moved) to be positioned exactly at the intersection of the grid lines. In special cases the point can also be inserted at only one grid line when the other coordinate is that of an existing point (see below, snap to existing points).

Snap to existing points

Snap to existing points enables points to be precisely located on either or both reference coordinates of existing points.

The snap point

The snap point is a special case of snap to existing points. In some cases, you may want to move a surface to a precise location e.g. (0.33, 0.46) not being a point on the grid nor an existing point of another surface. In that case:

- Create a new surface.
- Click the approximate position of the reference point.
- Change the coordinates to the exact position, e.g. (0.33, 0.46) in the Point editor.
- Press Insert (or Esc) to finish editing the surface, the point will appear with the mark +Snap point.
- Select the fix point in the surface to be moved (left mouse button) and move it to the location of the snap point. Do note that Snap to existing coordinates option must be checked.

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Once the surface has been moved, the surface containing the snap point may be deleted; this is not a strict requirement as surfaces containing only one point, will not be transferred to the .par format to be used in ODEON.

Coordinate snapping

When entering new points (clicking the mouse), coordinates of points will be truncated to the nearest snap, e.g. if the snap is 0.25 and the X-coordinate of the clicked position was 0.15, then the X-coordinate of the point will be 0.25, if the Snap to grid option is enabled. But it is still possible to fine adjust the coordinates in the Point editor (lower right corner of the Extrusion modeller). If Snap to existing points is enabled, then the X,Y (or Z) coordinates of already defined points are also snap-able.

Ortho snap

Enable Ortho snap if the surface to be drawn has many edge angles of 90 (or 270) degrees. The option can be turned on and off while drawing a surface.

Lock equal points

When this option is enabled it becomes possible to move points in multiple surfaces if the X,Y (or Y,Z or X,Z) coordinates are equal. This is useful for multi-level rooms where e.g. X and Y coordinates are identical for multiple points while the Z coordinate differs.

Snap to existing coordinates

Makes it easy to draw new points making use of horizontal or vertical coordinates in existing points – also when these do not match current snap size.

Lock H and V snap

If this option is checked then Horizontal snap size will automatically be updated when the vertical snap size is changed and vice versa.

Relative or absolute extrusions

Use the Ctrl+H shortcut to toggle between relative or absolute extrusions in the Surface editor table. When extrusions are displayed in relative measures an extrusion may be defined as Z=10 and dZ=5, telling that the extrusion starts at a height of 10 and has an extrusion height of 5. If toggling to absolute extrusion then the same extrusion is displayed as Z_1=10 and Z_2= 15 telling that it starts at Z=10 and ends at Z=15.

Modelling an array of surfaces

Each extrusion surface has a set of array properties associated with it (N_x, $Dist_x$, N_y, $Dist_y$, N_z, $Dist_z$), a set for each of the three main orientations in the room. These properties can be found in the Surface editor and define how many times the surface should be repeated in each of the main directions and the distances between the repetitions. This feature is typically used in order to create a number of columns, beams, tables or chairs with a regular spacing. When editing an array surface e.g. modifying a point, all the repetitions of the surface will be changed accordingly.

Explode an array of surfaces

If individual changes are needed, the arrayed surface must be 'exploded'. Once this operation has been carried out, the surfaces in the arrayed surface have been turned into individual surfaces which can be modified surface by surface (e.g. delete some of them). It is not possible to perform the reverse of the explode operation so before exploding an arrayed surface, make sure all operations common to the surfaces in the array have been carried out.

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Define Layers

For later management of acoustics materials inside ODEON, the extrusion modeller has layers. This allows you to easily assign materials to all surfaces on one layer in the Material list within ODEON. Create a layer with a name and colour in the layer box (above the surface editor).

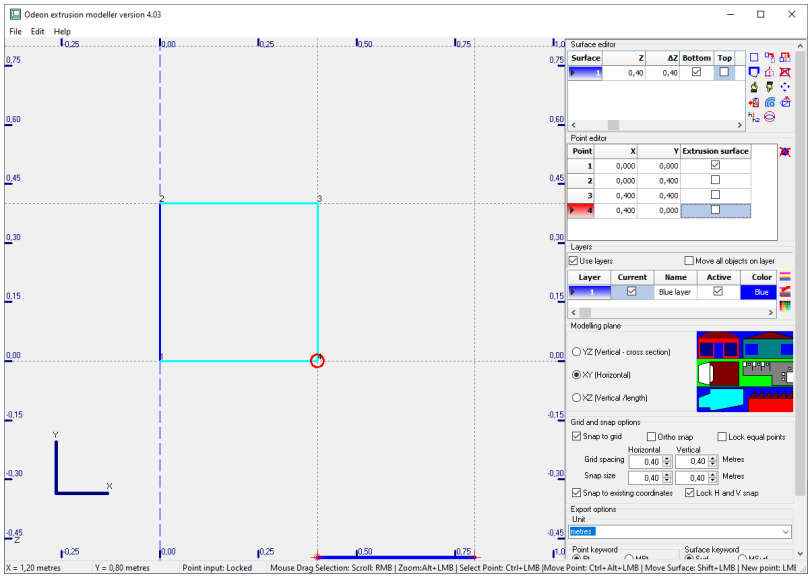
You can deactivate layers to make them invisible in the extrusion modeller but deactivated/invisible layers will still be loaded into ODEON.
The current layer (checked as Current in the Layer list) is the one that new surfaces are created on.
By checking Move all objects on layer it is possible to move multiple surfaces in one operation. It is possible to change the layer of an extrusion surface in the Surface editor allowing you to group surfaces on one layer prior to moving them.

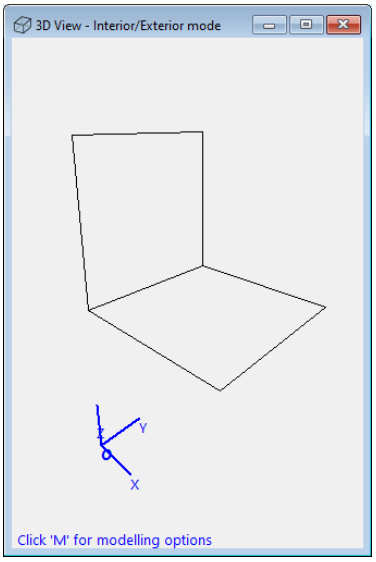
Modelling a chair

As an example, we will create a chair with the seat dimensions 0.4 x 0.4 and a back rest with the height of 0.4. Legs and other small details should be omitted. Therefore, if modelling a room in the XY Modelling plane then a chair may in effect be considered as an extrusion which excludes the top and three of its sides. To make things easier when modelling through the extrusion modeller, do the modelling around origin, then move the chair to its final location when finished. When modelling around the origin, it becomes easier to read the dimensions of the seat of the chair and to use grid and snaps without the need to calculate dimensions of the seat:

- Set the grid and snap size(s) to 0.4 metres.
- Click on 4 points of the grid, starting from x = 0 and y = 0, to form a square (seat of the chair).
- Press Insert or Esc to stop drawing (Insert or Esc toggles point input on/off). The last dotted line should change to a solid line.
- Change the Z coordinate to 0.4 metres in the Surface editor to define seat height.
- Change dZ to 0.4 metres in the Surface editor in order to define the height of the back of the chair.
- Uncheck Top in the Surface editor to disable the top surface.
- Only one side will be extruded (back of the chair).

After following the steps above, the extrusion modeller window should look like the first figure below. Then, clicking the ODEON icon in the Surface editor produces the second figure below.

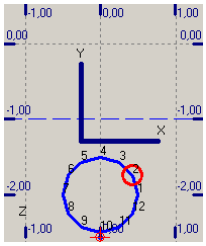




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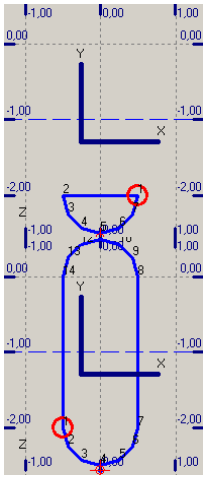
Creating a circular surface

To create a circular surface, first draw a line (a surface with two points) in order to specify centre and radius of the circle, then use the Ctrl+O shortcut to activate the circle tool and accept to create a circle from 12 points. If the circle tool is clicked when the selected surface contains less than two or more than three points then a help text is displayed, this text will also explain about ellipses.



Make a circle into a half-circle

Delete the 5 upper points in the circle in order to reduce the circle to a half-circle. At this point you should have created the half circle in middle of the Figure above.



Mirroring the surface

Following from the creation of a half-circle, the mirror functionality can be used to create a table plate with circular ends; select the horizontal mirror and specify the coordinate of the mirror line (in the Figures the coordinate was -1.00). Select the first of the two points to be connected across the mirror line and finally use the Mirror shortcut Ctrl+M to create the full table. The position of the mirror is easily changed if holding down the Shift key while pressing Right-mouse button and moving it – if performing a very significant move in the horizontal or vertical direction this will toggle between a horizontal and a vertical mirror line (blue dashed line).

Mirror manipulation	Mouse operation
Move mirror line /toggle between vertical and horizontal mirror line	Shift+Right mouse button

Creating a mirrored copy

Uses the current mirror line in order to create a copy of the currently selected surface

Create scaled copy of surface (Alt+Ctrl+C shortcut)

As above but a dialog appears, allowing input of a scaling factor.

Create copy of surface

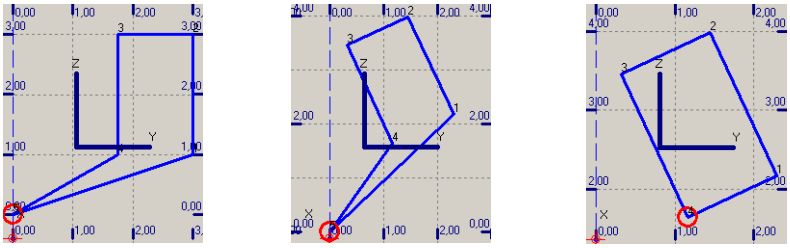
Will create a copy of the selected surface. The copy is offset slightly from the original one to make it visible.

Rotating a surface

To rotate a surface, select the point in the surface in which the surface should be rotated, then activate the Rotate dialog using the Ctrl+R shortcut and enter the number of degrees to rotate the surface (positive rotation angles always counter-clockwise - CCW). A surface cannot be rotated around a point which is not included in the surface. However, you may rotate the surface around an arbitrary point with the trick explained below.

- Select the surface.
- Bring it into editing state (Esc or Insert shortcut).
- Add the rotation point (it is not important where it is inserted in the sequence of points).
- Rotate the surface.
- Delete the rotation point from the surface (Del/Delete shortcut).

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To rotate a surface around a point which is not included in the surface, a) Insert a rotation point in the surface, b) Use the Rotate surface shortcut Ctrl+R to activate the rotation dialog and specify the rotation angle – in this case 25 degrees, finally delete the rotation point from the surface.

Examples

A few examples on extrusion models are installed with ODEON – the examples are located in the \ODEON<Edition Name>\rooms\oes Directory. The best way to learn about benefits as well as limitations of the extrusion modeller is to load the examples, investigate the surfaces (e.g. scrolling the point and surface tables) and to load the models into ODEON. This way the models can be investigated when being extruded.

Special extrusions

There are a few extrusion surfaces which are treated differently by the extrusion modeller:

1. A surface with an extrusion height of zero will produce one and only one 'horizontal' surface no matter if a Bottom or Top surface is selected.
2. An extrusion surface which only contains two points will only produce one 'vertical' surface, no matter if Bottom or Top surface is produced. If only a single edge is extruded into a surface with a height of zero, then no surface is produced.

2.9 Model check in ODEON

When you open a room file with Files|Open Room model, ODEON will check the validity of the file. However, this only checks whether the format is correct and the data is consistent, not if a meaningful geometry is defined. Furthermore, it will not check if the model is watertight, or conversely if there are leaks. So, after opening a room file, you may start by verifying if the geometry is meaningful and without errors.

This may involve:

- Viewing the room in a 3D View.
- Viewing the room in the 3D Render display.
- Analysing the geometry for unacceptable surface warps in the 3DGeometry Debugger.

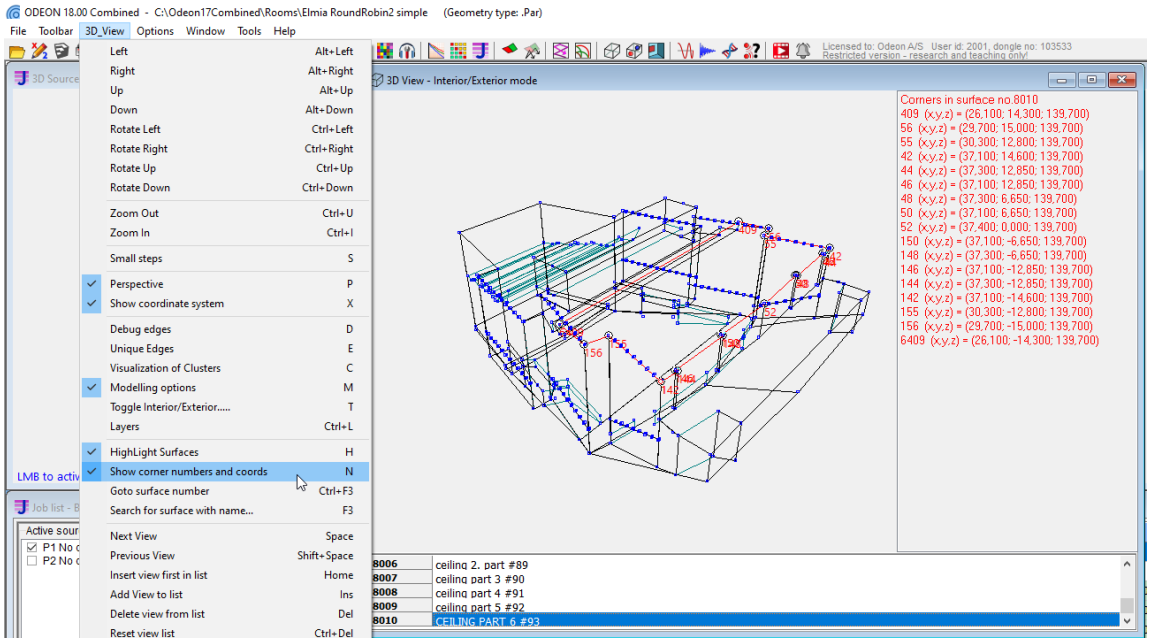
Analyzing the geometry for unacceptable surface overlap in the 3D Geometry Debugger

- Checking for missing surfaces in the room (forming holes in the geometry). The Unique edge's function available from the 3D View may help you (shortcut E).
- Testing water tightness of the room, using either 3D Investigate Rays or 3D Billiard.

3D View

The 3D View, displaying your room once loaded into ODEON, has a large number of features which can be useful when creating and verifying geometries for ODEON. For example, you can view the corners and coordinates in a selected surface using the N shortcut and display the coordinates of the corner closest to the mouse pointer using the M- shortcut.

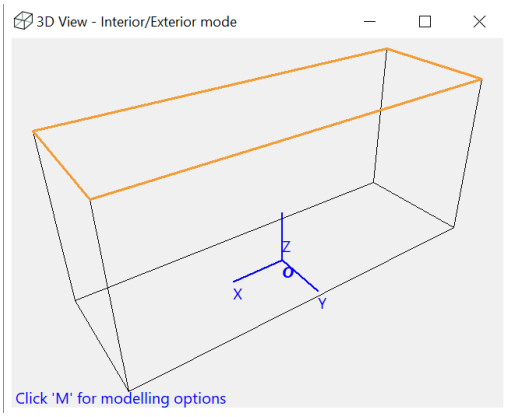
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Remember: Always check the context-sensitive menu that appears at the menu bar between the Toolbar and the Options menus. Please do so to view all functions available in the window you are currently working in, and their corresponding shortcuts. On the picture on the left, the 3D View window is active and therefore the 3D_View menu appears in the menu bar.

The perspective option (shortcut P) allows you to turn off the perspective of the room, to get an isometric display of the room. This may prove valuable when investigating warped surfaces.

The Unique Edges option (shortcut E) in the 3D View display shows edges, which only occur on one surface. Such an edge is "free"; it might be the edge of a free-hanging reflector, but it also could be the result of an error whereby two surfaces, which should join along an edge, do not.



Example: A box-shaped room is supposed to be modelled with 6 surfaces, but the user forgets to define the 6th surface in the geometry file. This room will have a hole where the 6th surface is missing. The unique edge's function will show where the missing surface should have been.

Using the 3D Render display for model verification

The 3D Render display is very useful for detecting holes in the geometries. Especially if stepping outside the model (Back-arrow shortcut) and rotating the model using the Ctrl+Arrow shortcuts. See the corresponding 3D Render dropdown menu for more shortcuts. When materials have not been assigned to all surfaces in the room, surfaces will appear in random colours making holes easier to spot. If materials have been assigned, the colours will by default reflect the acoustic properties of the surfaces, however it is possible to turn on the random colouring at will, using the R-shortcut. If the model contains layers, it is also possible to show the layer colours using the Ctrl+L shortcut.

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Remember: The 3D Render may occasionally fail to display complicated surfaces, including numerous holes correctly (typically surfaces created by CAD software using solid modelling techniques and subtractions) although the surfaces are perfectly legal with respect to ODEON. In these rare cases you may assure yourself that the model is in fact correct by putting point sources at various test positions and by conducting tests using the 3D Investigate Rays and 3D Billiard utilities.

3D Geometry debugger

Overlapping and warped surfaces should be avoided in the room model specified in the geometry file, but a certain amount of overlap and warp (by default 50 mm) is allowed without generating a warning. By overlapping surfaces is meant surfaces, which define a part of the same plane in space. In the simple case this can be because the surfaces are simply duplicates, another case could be a door, which has been defined in the same plane as the wall in which it is mounted. Overlapping surfaces should be avoided because it will not be clear which absorption coefficient should be applied at a reflection in case of overlapping surfaces with different materials.
Warps can lead to "holes" in rooms at edges of joining surfaces, with erroneous results as a consequence and the surfaces will not be well defined.

Using the 3D Geometry debugger in ODEON, a list of warnings and a corresponding illustration in a 3D display will be generated, whenever an overlap or a warp exceeds the value specified in the Room setup|Model>Air conditions dialog.

Overlapping surfaces are a tricky problem because it is usually invisible on 3D projections of the geometries, however such errors in the model may lead to unpredictable results, so *always* check models of considerable complexity for overlapping surfaces.

Testing water tightness using 3D Investigate Rays

Testing a new model for "water tightness" (i.e. whether it is completely closed) may be done using a 3D Investigate Rays window.

The room model may not be watertight if:
- Surfaces are missing from the model.
- Surfaces are unacceptable warped.
- Boundary surfaces have been assigned transparency coefficients greater than zero.
- Boundary surfaces have been set to the Transmission Wall type
- Boundary surfaces have been assigned Material 0 transparent.
- Sources are located outside the room.

Before investigating ray tracing, you will have to:
- Make the boundary surfaces of the room "solid" by assigning materials to them. For the moment it does not matter what the materials are, as long as they are not transparent (Material 0) or fully absorptive (Material 1). Go into the Materials List and assign, e.g. 10% absorption to all surfaces (use Ctrl+Ins to do this in one keystroke).
- Place a source somewhere inside the room. Sources are defined from the Source-receiver List. At first it may be a good idea to define a point source somewhere in the middle of the room.

Open a 3D Investigate Rays display and run it with, e.g. 1000 rays, with a Max reflection order of zero. This will test whether any holes can be seen from the source-position and should reveal any large problems. The tracks of lost rays will show outside the room boundaries, and indicate whereabouts in the room, the problems occur.

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If rays are being lost, and you have an idea of which part(s) of the room is /are "leaky", a number of things may be done:

- Run the 3D Geometry Debugger. Warnings will appear if surfaces have a warp or an overlap above the currently acceptable range. This may reveal slight warps of surfaces in the leaky region of the room which then have to be reduced as far as possible by revisions to the geometry file. If no error showed up you may reduce the value of Max. accept. warp in the Room setup at the Model|Air conditions page – to reveal smaller leaks in the model.
- Use the 3D View or 3D Render for inspection of the model to study the region(s) under suspicion. It may turn out that a surface is missing or does not join to its neighbours in the expected manner. It may help to zoom regions in question with the Highlight surfaces, Show corner numbers and coords and Modelling options switched on.

2.10 Combining geometries

It is possible to combine geometries imported from an external CAD program with geometry modelled in the Extrusion modeller or modelled in the parametric modelling format of ODEON. When a geometry has been imported in ODEON it will have the .par format. This is a text format and the content of different room-files can be copy-pasted together to one room file. This is done in the Odeon Editor  . Just copy the content from one room in the Odeon Editor and add to another room in the Odeon Editor then press "Save and Reload in Odeon" (the ODEON  symbol in the Odeon Editor).

Be aware that you need each surface number to unique. This, and other issues, can be solved by some facilities in the parametric modelling format: NumbOffset, CoordSys, Unit, MTranslate, MRotateX, MRotateY, MRotateZ, MScale, MReset and MPop.

Below is an example/outline which illustrates how a number of geometries can be merged together into one parametric file:

```
###
CoordSys X Y Z
.....1. model data.....
.....1. model data.....

NumbOffset 1000        ;avoid reusing point and surface numbers which have already been used
CoordSys Y X Z         ;swap coordinate axes as needed
MTranslate 0 15 20     ;Translate /move geometries as needed
.....2. model data.....
.....2. model data.....

NumbOffSet 2000
MReset  ; restoring default origo
CoordSys X Y Z; restoring default coordinate system

.....More model data ???
###
```


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3 Sources and Receivers

Once the geometry of a room has been loaded into ODEON, sources and receivers have to be placed through the Source receiver list (shortcut Shift+Ctrl+S), as described in the *Quick Start Guide*. This manual will not repeat the content of the *Quick Start Guide*, so please read that first.

The sources could be an omnidirectional point source, a person speaking, a loudspeaker, a road with traffic, a large industrial machine, or something else.
Depending on the sound source you need, four different types of sources are available in ODEON:

- **Point Sources**. *Available in all editions.* Most common type of source where sound radiates spherically from a point. It is possible to define the directivity pattern of a point source, so many cases can be simplified to the use of point sources. Used e.g. for omnidirectional point sources, for people speaking, for instruments or simple loudspeaker setups.

- **Line Sources**. *Available in ODEON Industrial and Combined*. Sound is radiated from a line. Used e.g. for roads with traffic or pipes with running water.

- **Surface sources**. *Available in ODEON Industrial and Combined*. Sound is radiated from one or multiple surfaces in the room. Used for e.g. industrial machines or crowds of people in restaurants.

- **Array Sources**. *Available in ODEON Auditorium and Combined*. Used for loudspeaker array setups.

The receiver has a very simple form being just a "point" uniform mono-microphone. For auralisation (see Chapter 7) the exact direction of the head is needed, this is something which can be adjusted in the JobList.

3.1 Generic point sources

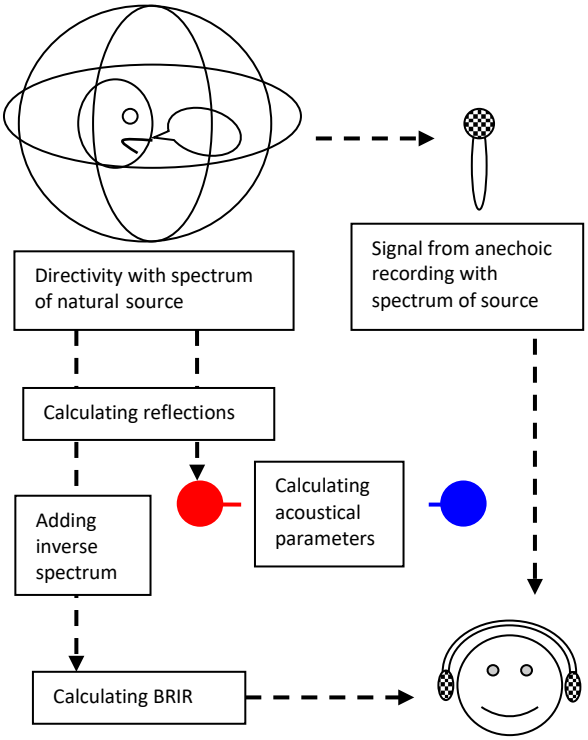
Generic point sources such as the OMNI or SEMI directional sources are typically used for calculating the frequency response and the parameters characterizing the room-acoustics. Generic sources are typically defined mathematically.

3.2 Natural point sources

With "natural sources", we refer to sources such as human voice, an acoustical instrument or similar. Natural sources are typically used for auralisations and/or calculation of acoustical parameters that depends on a specific sound power of a natural source. E.g. speech intelligibility of a person or sound pressure level by a smaller machine.

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A recorded signal for auralisation is associated with the directivity pattern of the actual source presented during the recording. In an auralisation, the directivity pattern for natural sources in ODEON is used together with the recorded frequency spectrum of e.g. a voice. If this isn't handled correctly, this will result in an auralisation where the overall frequency response is included not once but twice; first time through the directivity pattern which includes the overall frequency response, second time through the recorded source signal, which inherently includes that response.



For example, in order to estimate SPL or STI correctly and for calculation of acoustical parameters, it is desirable that the true frequency content is included in the directivity pattern. However, for an auralisation, the directivity pattern should be equalised with the inverse spectrum of that recorded at the font axis of the natural source signal (i.e. the wave file with human voice recorded with a microphone at the front axis).

From ODEON version 8.5 and up, it is possible to create correct estimates of parameters from natural sources - and at the same time create correct auralisation, where the overall spectrum is included only once. It is necessary to use a source marked *Natural*. ODEON has some directivity patterns which have the word *Natural* attached to their names e.g. BB93_Normal_Natural.So8. When natural directivity patterns are selected from within the Point Source Editor, a green natural-label is displayed next to the equalization input fields.

If having existing directivity patterns of natural sources which are not marked natural, this can be done by using the Tool>Directivity patterns|Mark So8 file as natural directivity. When creating new directivity patterns, this information is part of the input data.

Always use the _Natural versions of the directivity files when defining new natural point sources. The old versions of the files are kept in \Old_So8\ a subdirectory to the \Dirfiles\ directory. If you wish to use the old directivities in old /existing projects, then open the Source receiver list and click the Repair broken directivity links button (shortcut Ctrl+L).

Samples on natural directivity patterns (BB93_Normal_Natural, BB93_Normal_Raised and Soprano ref. 42).

The BB93_Normal_Natural source type (BB93, 2015) corresponds to a male speaker with a normal vocal effort. The gain and EQ fields in the Point source editor (inside ODEON) should be set to zero. This source is also a reasonable approximation to a female speaker, except that the 63 and 125 Hz band should be ignored.

To simulate a trained speaker addressing an audience in a raised voice, use the BB93_RASIED_NATURAL source. This has the same directivity as BB93_Normal_Natural, but the levels in the eight octave bands are higher.

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The directivity pattern of Soprano ref. 42 is the directivity of a soprano singing opera (Parati, et al., 2003).

3.3 .CF1 .CF2 Common loudspeaker format, CF1 and CF2 files



ODEON version 8 and up supports the Common Loudspeaker Format which is an open format for loudspeaker data, supported by several loudspeaker manufacturers as well as manufactures of software programs such as ODEON. The Common Loudspeaker Format was developed and also maintained by the *CLF-group*. It is an open, though secure, file format for loudspeaker performance data and polar plots. Loudspeaker manufacturers can use the CLF format to supply data to end users of professional room acoustic computer programs.

CLF files are *binary distribution files* having the extensions CF1 and CF2. These files are created by loudspeaker manufactures or independent measurement services which have obtained a license key for the CLF authoring kit. The need for an authoring key for the authoring kit ensures that data distributed in the CLF format can be traced back to the author and that data can't be modified by third party. In order to view all data in the CLF format you can download a free viewer from the CLF group home page.

CF1 has a frequency resolution of 10°, 1/1 octave and CF2 has a frequency resolution of 5°, 1/3 octave. If data are available in either format for a selected loudspeaker then the CF2 format should be preferred because of its higher angular resolution. Currently ODEON does not make use of the higher frequency resolution of the CF2 format except for loudspeaker array modelling where ODEON makes use of the higher frequency resolution as well as of phase data (if available) for calculation of distance dependent directivity of the loudspeaker arrays (which are composed from multiple units added with phase).

The CLF Group is providing a set of free tools for data editing, conversion from text to binary format, and viewing binary data. This allows loudspeaker manufacturers and independent measurement services to create, view and verify binary distribution files and ensures that it is easy for loudspeaker manufactures to make data available. Links to loudspeaker manufacturers currently providing *binary distribution files* can be found here. If apparently the data of interest is not available from a manufacturer of interest, then assist the CLF-group by encouraging the manufacturer to make such data available – free tools for this purpose can be obtained at the CLF group's homepage.

3.4 Directivity files in the EASE 3 and EASE 4 formats

Since ODEON 16, .Lob + .Spk directivity files (EASE 3 and EASE 4) are supported. These files contain directivity patterns in 5° resolution, 1/3 octave. These data are supported for use with simple point sources where they provide and angular resolution of 5° and a frequency resolution of 1/1 octave. Currently ODEON does not support the use of .lob and .spk files for loudspeaker array modelling. A set of directivity in the EASE 3 and 4 formats may come with a number of files having the extensions .lob, .spk, .fed, .ffc, .fvt and .phs. Currently ODEON only makes use of .lob and .spk files which defines the directivity balloons and the sensitivity. Both the .lob and .spk files must be present for ODEON to recognise and use the given directivity. It is though recommended that all the files are copied to the ODEON's DirFiles folder, as they contain extra data, like *phase information*, *geometry of the speaker* etc. ODEON is able to display a drawing of the loudspeaker cabinet geometry directly in the Source 3D View.

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Unlike the CLF data, the .lob and .Spk data formats does not ensure data integrity, it is not possible to see if data was created by loudspeaker manufactures or independent measurement services or if it was created by someone needing the data and entering some data themself – therefore it is recommended that these data format should only be downloaded from trusted source (e.g. directly from the homepage of the loudspeaker manufacturer. If data is available in the CLF format then these data should be preferred! – and again you are urged to prompt the loudspeaker to make data available in the CLF format if they are not.

File location for directivity files

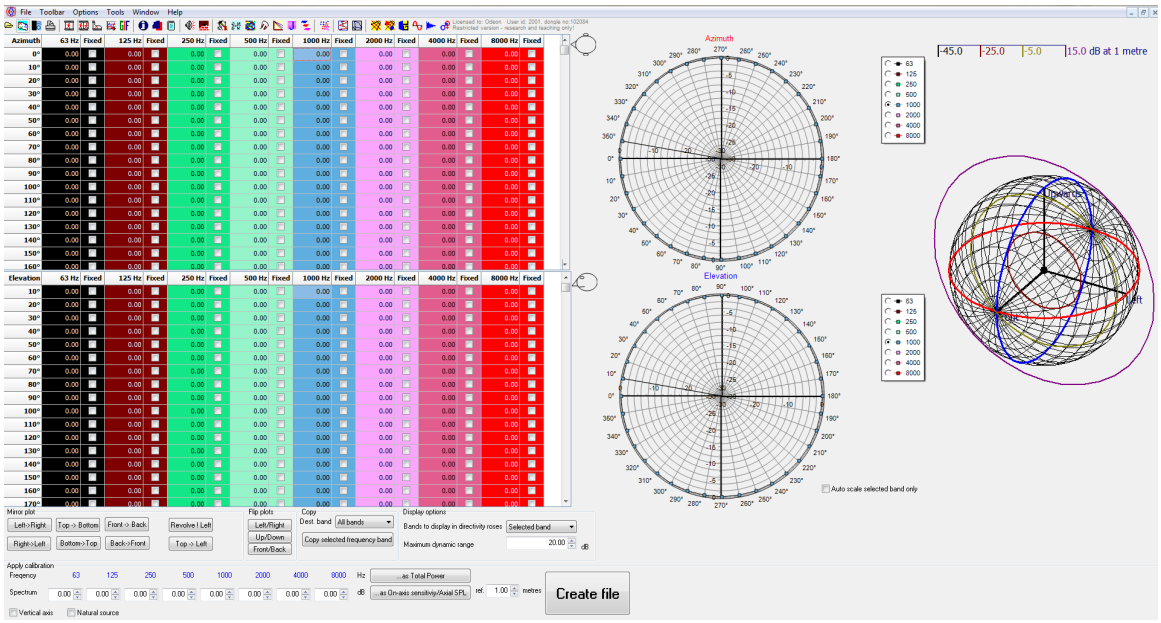
Regardless if files are in the .cf1, .cf2, .lob + .spk or in ODEON's native formats (.So8, .SoCF1Tab or .SoCF2Tab), the files should be stored in ODEON's directivity directory as specified inside ODEON at Options>Program setup>DirFiles folder. The files may be stored in sub-directories to this directory allowing loudspeaker directivities of different brands to be located in separate directories e.g. C:\ODEON…\DirFile\ManufacturerA or C:\ODEON…\DirFile\ManufacturerB. We have taken the opportunity to create a number of folders for manufactures who supply loudspeaker directivity files in the CLF format. Using these predefined directories, it is easier to move a room from one PC to another without breaking file linkage.

3.5 Creating directivity patterns in ODEON's .So8 format

Tools for creating directivity patterns in the ODEON .So8 format can be found at the Tools>Directivity Patterns>Create directivity pattern in plot editor menu entry inside the ODEON program. The tools allow you to expand the set of source directivity pattern files available for point sources in ODEON. The ODEON directivity pattern file (Version 3 or later) contains information on the sound levels for the eight frequency bands 63 Hz to 8 kHz in dB for each 10° azimuth and 10° elevation. These files are binary and have the extension .So8. An example on a directivity pattern is the pattern stored in OMNI.SO8.

Entering a directivity plot using the Directivity polar plot editor

The easiest way to enter a new directivity plot is to use the built-in polar plot editor which allows building a directivity plot from a vertical and a horizontal polar plot. Click Tools>Directivity Patterns>Create directivity pattern in plot editor. The following window appears:



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Enter the dB values (sound pressure level) for the horizontal and vertical plots at the selected frequency band in the corresponding tables. The angular resolution is 10° degrees. If data is not entered for all angles (e.g. if the data are not available) ODEON will do interpolation between the angles entered. For angles between both polar plots, ODEON will perform elliptical interpolation.

Equalization

If the source to be used in ODEON has a fixed frequency dependent sound power level, the equalization option in the Polar plot editor is used for entering the dB values.

Calibration

Three different options are available in the Polar plot editor:

- If No calibration is selected, ODEON will use the SPL dB values as entered in the polar plot table, adding the equalization values entered. This option is typically used if the source is a loudspeaker.
- If Calibrated source is selected, ODEON will add the equalization if entered, then shift the resulting SPL's of the source in order to obtain a reference sound power level of 0 dB re 10^{-12} Watt at the selected Calibration frequency band (typically 1 kHz). This calibration type is typically used when a generic source with an adjustable level is needed for calculations, such as the OMNI or SEMI directivity pattern,
- If Sensitivity calibration is selected, the SPL's of the source will be shifted in order to obtain the SPL in dB on front axis of the source at the distance specified as Ref. distance metres at the selected Calibration frequency band. This calibration type is typically used if the free field sound pressure level measurement is available for a natural source.

Maximum dynamic range

The *minimum level* will be *Max level* minus *Maximum dynamic range*. If the range is large the display may be difficult to interpret /view in the directivity viewer. The source will usually have its max levels on its axis.

Odeon directivity text import format

Normally the text format should not be necessary to use, as most common sources are defined already in ODEON or available on the CLF website.

The data entered in the text format should be in relative calibration across frequencies, but doesn't need to be in any absolute calibration. The absolute calibration is an option, from within the program as described under the section below: "Creating a new directivity pattern using a text file as input".

The first non-comment line of the input file indicates whether the data is for:

- POLAR set containing horizontal and vertical polar plots, for sources where only a horizontal and a vertical plot are known, e.g. a loudspeaker.
- FULL set, for complex sources where directivity data is known for each 10° Azimuth and 10° Elevation.
- SYMMETRIC set, for symmetric sources, e.g. a trumpet.

The second non-comment line in the input file indicates whether the data represents a Natural source such as a musical instrument, or a person speaking - and also if it represents a source such as a loudspeaker which does not include the frequency response of the source signal. The purpose of this Boolean is to make auralisation correct for natural sources set NATURAL to:

- TRUE for sources such as musical instruments.
- FALSE for sources such as loudspeakers.

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Each of the subsequent lines of the input file should contain sound pressure levels in dB for a complete 180° of elevation (from the forward axis to the backward axis). The resolution must be 10°, hence each line contains 19 values (0°, 10°, 20°, …, 160°, 170° and 180°).

Lines containing comments, and empty lines, may be inserted anywhere in the ASCII input file, as long as they do not come between data items, which should occur on one line. Comment lines must begin with a colon (:), a semicolon (;) or an asterisk (*).

When only horizontal and vertical polar plots are known (POLAR)

The first non-comment line of the file should start with the word POLAR. In the polar case, there are four lines of data for each frequency band. The first four lines are for 63 Hz, the next four for 125 Hz, and so on.

For a given frequency, the first and last values must agree on all four lines, since all the polar plots meet at the front and back of the plot. The first line of a group of four is the upward vertical polar plot as seen from in front of the source (12 o'clock plot). Then the left horizontal plot (9 o'clock plot) appears downward vertical plot (6 o'clock plot) and finally the right horizontal plot (3 o'clock plot). As a minimum there must be 1 + 4 * 8 lines in a polar input file.

Elliptical interpolation

When ODEON translates the polar input file it has to interpolate values between the four polar planes given in the input data. This is done using elliptical interpolation independently for each frequency band, creating the 8 x 4 plots missing between the four input plots.

An example: Polar_Omni.dat The polar input format can be found in the DirFiles\So8_ASCII_input_file_samples\ directory, created at the installation of ODEON.

When the complete directivity characteristics are known (FULL)

The first non-comment line of the file should start with the word FULL. In the full case there are 36 lines of data for each frequency. The first 36 lines are for 63 Hz, the next 36 lines for 125 Hz, and so on.
As a minimum there must be 1 + 36 * 8 lines in a full input file.

- 1st line is vertical upper plot 0° (12 o'clock plot, when looking from the front of the source towards it, e.g. at a loudspeaker membrane).
- 10th line is horizontal left plot 90° (9 o'clock plot).
- 19th line is lower vertical plot 180° (6 o'clock plot).
- 28th line is right horizontal plot 270° (3 o'clock plot).

An example; Full_Omni.dat The full input format can be found in the DirFiles\So8_ASCII_input_file_samples\ directory, created at the installation of ODEON.

When the directivity pattern is rotationally symmetric (SYMMETRIC)

The first non-comment line of the file should start with the word SYMMETRIC. In the symmetric case there is one line of data for each frequency.

As a minimum there must be 1 + 8 lines in a symmetric input file. The symmetric sources could be a Trumpet or the Omni directional source. An example; Symmetric_Omni.dat on the symmetric input format can be found in the DirFiles\So8_ASCII_input_file_samples\ -directory, created at the installation of ODEON.

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Creating a new directivity pattern using a text file as input

Once the text input file has been created in one of the formats specified above (e.g. in the ODEON editor; ODEONEdit), it can be translated into an ODEON Directivity file, which can be applied to any point source from within ODEON.

To translate the created text file into an ODEON directivity file:

- Select Tools|Create directivity (.So8) from ASCII file (.DAT).
- Open the input file you have created.
- Specify the name of the directivity file pattern you wish to create.
- Select whether you wish a Calibrated source or not.
- Apply calibration data as prompted for.

Applying Calibration

When creating a new directivity file you will be asked whether to create a calibrated source or not:

Calibrated source (Sound Power Level = 0 dB re 10E-12 W at 1 kHz) ? [YES / NO]

Calibrated Sources

Press [YES] if a generic source with an adjustable level is needed for ODEON-calculations.
An example on this could be the OMNI or SEMI directional directivity pattern. When selecting a calibrated source, no data apart from the ASCII input file are required. The directivity represented by the text-file is preserved, but the values are simply shifted by a constant amount (the same for all bands), so the sound power level of the source is 0 dB re 10^{-12} Watts at 1 kHz. Please do note that the power in the other bands may differ from 0 dB. You may still alter the overall power response of the source by applying an EQ, however the power at 1 kHz will always end up as 0 dB, and the other bands shifted accordingly.

NON-calibrated sources – Electro acoustical sources, machinery, natural sources etc.

Press [NO] to preserve the sensitivity of an electro acoustical source or the absolute level of natural source, e.g. a human voice. When selecting the NON-CALIBRATED source you are allowed to enter equalising, electric losses (zero for natural sources) and sensitivity at a selected frequency band (zero for natural sources).

The addition of electrical sensitivity, electrical input power and electrical loss values completes the data necessary to generate a source directivity file directly readable by ODEON 3 or newer.

Other directivity text import formats

Odeon supports the text import format used as input for generating binary CLF files. The format is specified in the CLF Trial Authoring kit available on the CLF website. You will though probably not write data in this format yourself, but it may be used for importing data exported from other software such as EASE SpeakerLab Pro. Odeon will store the imported data in its own native format .SoCF1Tab and .SoCF2Tab – unlike the CLF data these data are not traceable therefore encourage that you only make use of these files for internal use and that you do not distribute them to third party. Similar do not make use of these files from an external source.

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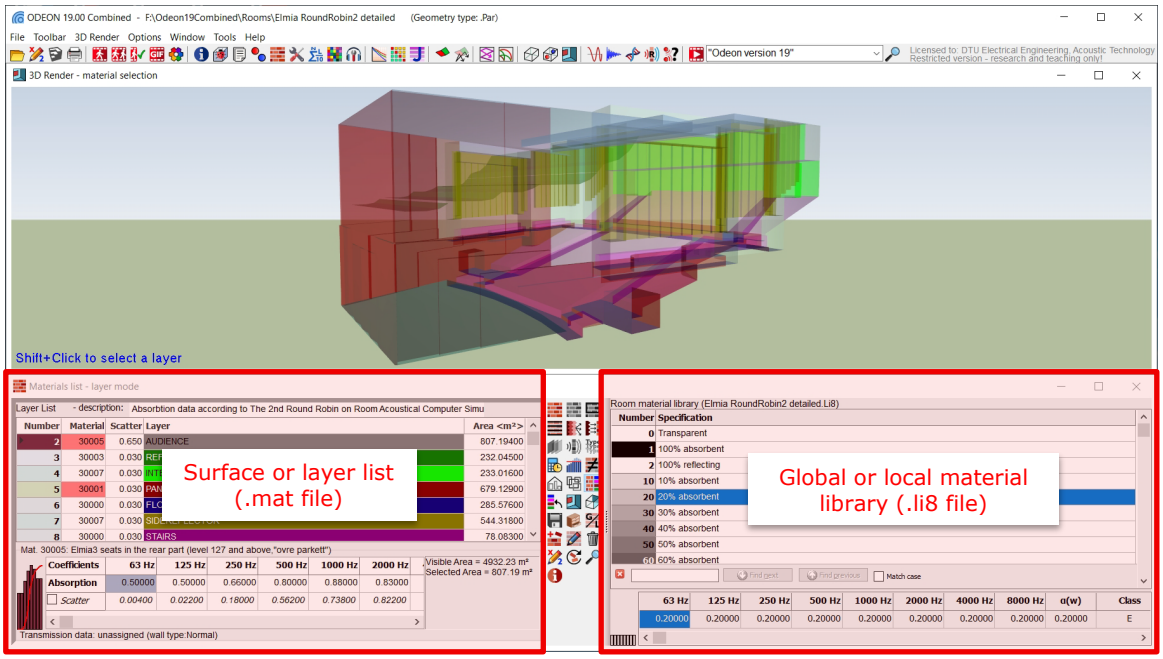
4 Materials

When the room geometry has been created and sources and receivers have been placed, a next important step is to assign the acoustic materials to the surfaces of the geometry.

The Material list is described in short in the *Quick Start Guide* (also available using the Ctrl+F1 shortcut from within the ODEON software). This manual will not repeat the content of the *Quick Start Guide*, so please read that first.

4.1 Overview of the Material list

ODEON's material interface is separated into an upper window, displaying the room's geometry, and a lower window containing information on the materials. The lower window consists of two different lists: a *Surface list/Layer list* on the left and a *Material Library* on the right. The left side contains information on the elements of the room geometry – this can be either a list of surfaces (in Surface mode) or a list of layers (in Layer mode). The right side is a material library, containing materials which can be assigned to the geometry. The library can either be global or local (i.e., specific to a room). The Material list is connected to the 3D Materials window; when selecting a surface in the Surface list, the surface is automatically highlighted in the 3D Materials window.



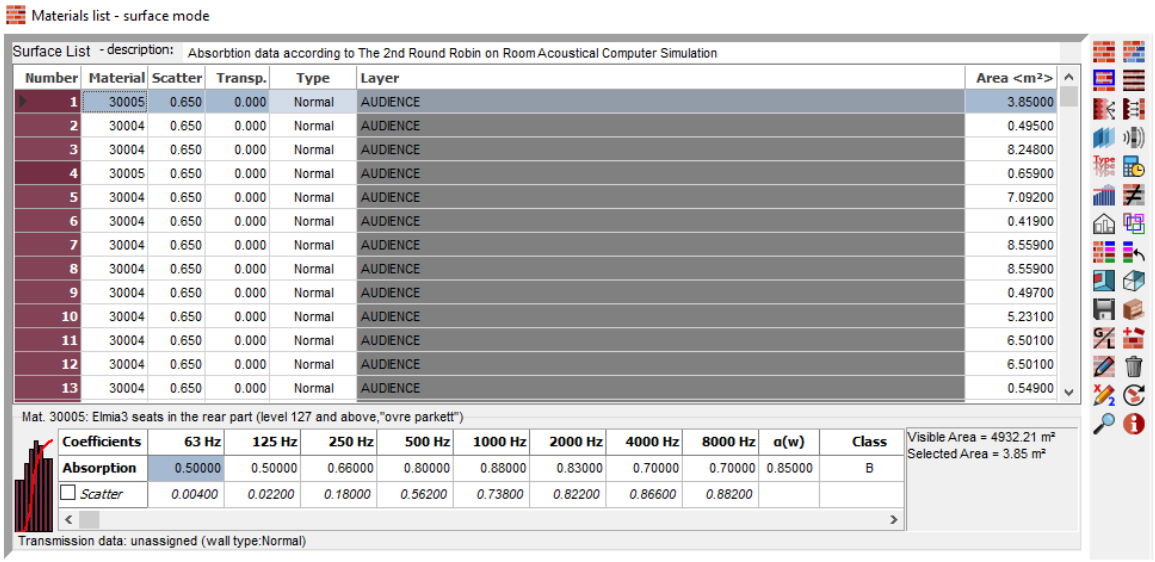
Left side of the Material list: Surface list or Layer list

In the left side table, you will find the material specifications assigned to the surfaces of the room. The list consists of either all surfaces in the room if you are in Surface mode, or a list of layers in Layer mode. A layer is essentially a group of surfaces sharing the same material properties and, in most geometry import procedures, layers can be inherited from the 3D model file (see more in Chapter 2). You can switch between Surface mode and Layer mode by clicking on . The Material list window indicates in which mode you are. In addition, the left table changes names accordingly (Layer list or Surface list).

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The information displayed on the left-side list is stored with every room, as a .mat file and it contains all the materials assigned to the surfaces in the room, as well as any modifications made on their absorption coefficients. These are the active absorption coefficients which will be part of the calculations. They are not affected by any changes made to the Material library.

Options and displays differ in Surface mode or Layer mode. The following covers the options in Surface mode, and the differences occurring in Layer Mode are explained in the next section.



Description

Optional description of the material configuration. This is useful if you wish to study different room configurations. You can save up to 10 versions of the list in the Material list archive, and the description can help you to recognize them. See more in Sec. 4.4.

Surface number

The Surface number is a unique number assigned to each surface in the geometry file. ODEON uses the surface number to attach the correct material data (and grid surfaces, reflector surfaces etc. elsewhere in the software). When importing the geometry from SketchUp with the SU2Odeon plugin, the numbers are generated and stored in the SketchUp model. This ensures that numbers stay consistent even when making changes to the SketchUp model and exporting it again. When importing a geometry from other formats (e.g., .dwg, .dxf, .3ds), the surface numbers will be generated by ODEON. The numbering may not be the same if the geometry is modified and reimported (e.g., deleting, adding or changing some surfaces). Therefore, when reimporting geometry, you should ensure that data such as material properties are still correct.

With ODEON 19, the Reassign materials by layer tool allows reassigning material properties to the surfaces assuming all surfaces on each layer had the same material (absorption and scattering).

Note: The colour of the number column gives a visual representation of the frequency dependent reflectance of the given material by mapping its reflectance onto a visual colour composed by the three colour components Red, Green and Blue. If the colour is close to red, it means that the material primarily reflects low frequencies. If it is close to green, it primarily reflects mid-frequencies. If it close to blue, it primarily reflects high frequencies. Similar if the material is white, it is good at reflecting all frequencies, if it is black, it reflects little or nothing and if grey scale it reflects equally at all frequencies (Christensen, 2001).

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Material number

The Material number corresponds to the material assigned to the surface, as listed in the Material library. There can be differences between the material in the Surface list and the corresponding one in the Material library, if it has been modified in either of the two lists and it has not been reassigned.

Scattering coefficient

The Scattering coefficient determines the amount of scattering introduced by the surface, due to its roughness profile. By default, the scattering coefficient is for the logarithmic mid-frequency (707 Hz) and is automatically expanded to cover the full frequency range applying a typical frequency function. It is assigned per surface, unless a material with an active scattering profile has been assigned. The default value is 0.01 (1%) and it is indicated in yellow if you have not changed it. This default value is very low in order to be sure to highlight potential echo problems that may occur in the room. Once such problems have been dealt with, the scattering coefficient can be assigned a more realistic value, typically 0.05 (5%) for fairly flat surfaces. For further details, see more in Sec. 4.7.

Transparency

The Transparency coefficient can be used for surfaces with openings or with high porosity (like curtains), which could let sound travel through without being absorbed. Then, these openings do not have to be modelled explicitly. For example, a layer of blinds being 30% open can be represented as one surface with 0.3 transparency. By default, surfaces are not transparent (transparency 0%). See more about transparency in Sec. 4.8.

Remember: Transparency should not be used for transmission calculations. See more about Transmission in Appendix B: Specify Transmission Though Walls.

Type

ODEON allows four Surface types to be assigned:

- *Normal*: default option, to be used in most cases.
- *Exterior*: the surface is considered as an exterior surface.
- *Fractional*: the surface is a part of a larger group of surfaces.
- *Transmission*: to use when sound is transmitted through the surface to another room.

See more in Sec. 4.9.

Surface name

The Surface name is only used in models which were built manually in a text editor (see Appendix H: Modelling rooms in the ODEON Editor). In most cases when the model is imported, the Surface name is the same as the name of the Layer – in which case the Surface name column will be hidden.

Layer

This column shows the name of the layer which contains the surface in the SketchUp model, or in your CAD application if the model is imported in the .dwg or .dxf file formats. For .3ds and .obj file, the layer name corresponds to the name of the material used in the CAD software (e.g., in 3D Studio Max). In ODEON, it is possible to define the layer names in the ODEON Editor.

Area

This is the calculated surface area of the surface. Occasionally, a surface can get a wrongly calculated area which can even turn out to be 0. This will be the case if the edges of the surface are crossing each other e.g., for a so-called *butterfly* surface. It is always a good idea to simplify the model and eliminate such surfaces. If multi-selecting several surfaces – the **sum of the selected**

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area is calculated and listed in the right side of the absorption and scattering table below the surface table. In Layer mode, the value will indicate the surface area of the entire layer instead.

Absorption and scattering table

The table below the Surface list shows the following data:

- **Absorption coefficients** assigned to the surface, in octave bands. The coefficients can be edited in the table. This will update the coefficients of all surfaces which have been assigned this material. However, changes do not affect the corresponding material in the Material library (right table).
- **Scattering coefficients** for the material, in octave bands. If the Scatter checkmark is checked, the scattering coefficient values of the material are used for all surfaces using this material, instead of the scattering coefficient in the surface list which will be greyed out. The frequency-dependent scattering coefficients may come from the material library (if provided by the material manufacturer) or it can be edited manually in the table.

Layer mode

The Toggle surface/layer mode button  makes it possible to toggle to the Layer mode. In Layer mode, the surfaces of your model are gathered by layer, which greatly simplifies the list (typically, you would only have a handful of layers, compared to hundreds of surfaces). The material and the scattering coefficient can then be assigned to all surfaces of the same layer at once. In layer mode, the Surface list is replaced by a Layer list and only the relevant columns are displayed (Layer number, Material, Scatter, Layer and Area). It is not possible to edit the transparency and the type of surface in Layer mode.

Material library (Right side of the Material List)

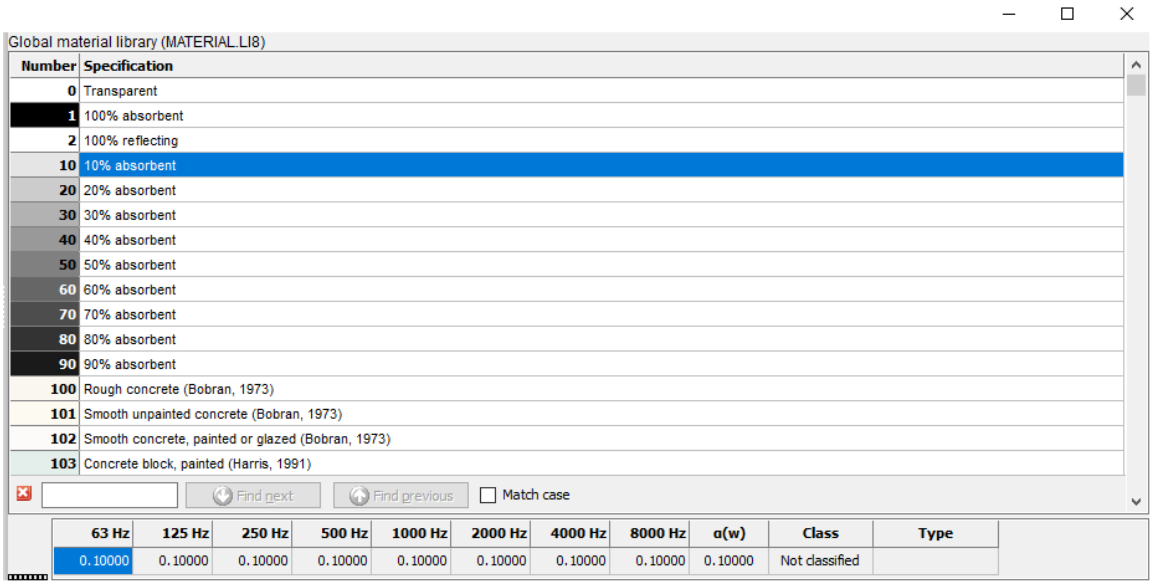
The Material library is a list of materials that you can use for your projects. You can add new materials, delete existing materials and change them as needed (see Sec. 4.3). The materials in the list can be defined as a set of absorption coefficients per octave bands, by an underlying physical model (via the Material Calculator) or by importing manufacturer data (octave or third-octave band absorption coefficients, plus scattering coefficients optionally).

The library can either be global or local (i.e., specific to a room). The Global material library is the default library of materials available in ODEON. This library, and any changes you make to it, will be available every time you start a project on your computer. The Global library is stored with ODEON on your PC (by default, as Material.Li8), so if you make changes to it, it will be different from the Global library on another computer. This does not prevent projects from being sent back and forth between colleagues, because the .mat file is not affected by changes to the library file. You can make a local material library by pressing the  Toggle between global and local room library button. This library file is saved as a .li8 file with the room's name, and it will only be active for that specific room. This is useful to keep certain materials local, without overpopulating the Global library and keeping it as generic as possible for other rooms. The title of the material library above the table changes accordingly, and it indicates the name of the .Li8 file in use. You may delete the local library if no longer needed using the ALT+Del shortcut, listed in the Materials context-sensitive menu.

You can change from local to global library as you please, the Surface List/Layer list will not be affected by any change unless you actively reassign materials.

Tip: If you click the Toggle between global and local room library  button, all materials with different definitions in the Surface list will be created as new ones in the (local) Room material library.

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Number

Unique identifier for the material. ODEON follows a numbering system which is explained further in Sec. 4.2.

Specification

Short description of the material and reference to documentation. The reference can include a link to the manufacturer's internet page or a measurement report. URLs can be written as http://odeon.dk or www.odeon.dk, and they are displayed as active links. Clicking the link will open the specified page in your default internet browser.

Special materials

The colour of the line in the list indicates the origin of the material.

- White: the material is simply specified by absorption coefficient values in octave bands.
- Blue: the material is derived from the Material calculator. See Sec. 4.5.
- Orange: the material is imported from a manufacturer database, and it may contain extra information (third-octave values, etc.) See Sec. 4.6.

Absorption table

The absorption coefficients per octave band are displayed in the lower table, as well as the weighted absorption coefficient $\alpha(w)$ which is a broadband parameter defined in (ISO 354, 2003), and the absorption class. The last column "Type" indicates if the material has been created with the Material calculator or has been imported from a manufacturer database. As opposed to the table in the Surface list, the table cannot be edited directly in the Material list.

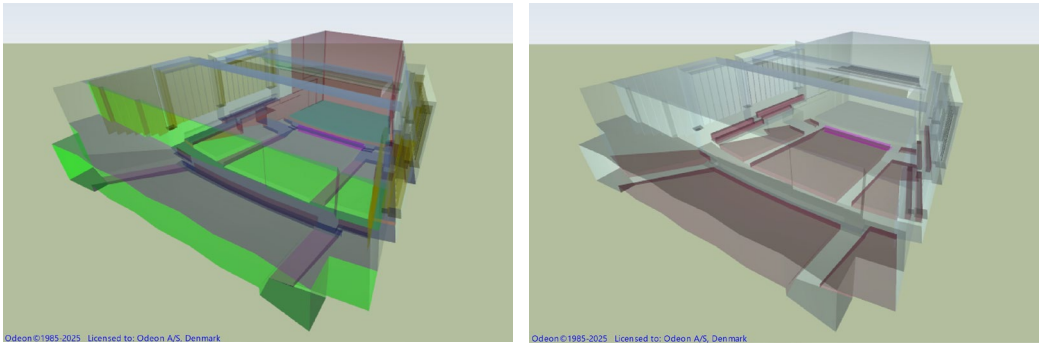
Tip: Clicking the Display material info button will display further information if supplied by the manufacturer (graphs of 1/3 absorption, 1/3 octave scattering and 1/3 octave diffusion as well as images, links to reports etc.)

3D Model

A 3D model of the room is displayed on the upper half of the display. By default, the room's model is displayed in a 3D Render mode, which is a great interface to get an overview of your assigned materials. It is possible to revert to ODEON's legacy 3D wireframe view by clicking on .

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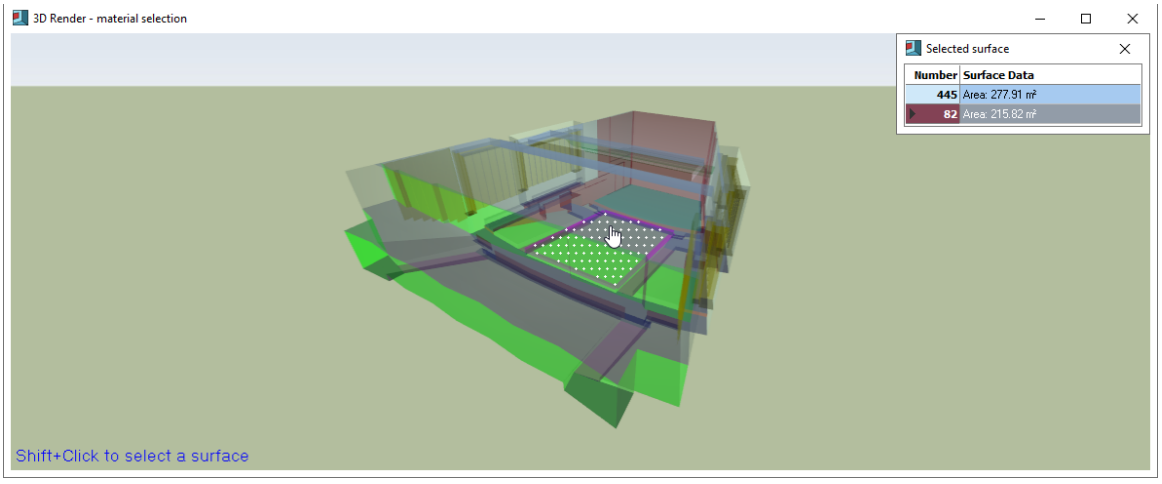
The surface colours in the model correspond to the layer colours by default. These can be set in your CAD software or SketchUp before importing the model, or via ODEON's 3D render view. Alternatively, click on in the Material list toolbar to display material colours based on the absorption coefficient of each surface.



Left: material 3D render with layer colors. Right: material 3D render with material colors.

The observation position is by default outside of the model, and the X-Ray option is activated so that you can see through the whole model. You can freely move inside the 3D view, and when the observation position is inside the room, the surfaces become solid. You can always choose different display options in the 3D render context-sensitive menu.

In order to select a surface, either select a line in the surface list table or SHIFT+Click in the 3D Render model. When X-Ray is activated, it might be possible that several surfaces are aligned with your cursor. In that case, a menu appears on the top-right corner of the 3D Render allowing you to select one of these surfaces. In the screenshot below, the selected surface is the audience area (Surface 82), marked by dots and a magenta contour. The mouse cursor was also aligned with Surface 445, corresponding to the ceiling. This is why it is also displayed in the upper-right table.



4.2 Categories in the Material library

By default, the Material library follows a numbering system which you can use to keep it organised.

The default material database is divided into different categories (e.g., gypsum, wood, etc.). Most of the categories span a range of 1000 materials (except for the first two). In each category, the first

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100 materials should be reference materials. ODEON has suggested a few to begin with. Hereafter it will be possible to include 9 different manufacturer lists (e.g., one manufacturer with numbers within 1100-1199 and another within 1200-1299). Following this convention, the leftmost digit defines the type, the next one the manufacturer and the last two the specific material. Some of the materials come from (Harris, 1991), while others have the reference and link included in the Material description, inside ODEON.

The numbering of the main categories is as below:

- 0-99 Special materials.
- 100-999 Concrete.
- 1000-1999 Brick.
- 2000-2999 Ceramics.
- 3000-3999 Wood.
- 4000-4999 Gypsum.
- 5000-5999 Steel.
- 6000-6999 Vinyl/Plastic/Plexiglas.
- 7000-7999 Carpets.
- 8000-8999 Curtains and blinds.
- 9000-9999 Natural materials (e.g. sand, grass, water, etc.).
- 10000-10999 Doors/Windows/furniture/inventory (e.g. organ pipes, ventilation grills, bookshelves).
- 11000-11999 Audience areas +/- people.
- 12000-12999 Mineral wool.
- 13000-13999 Wood wool and alternative porous absorbers.
- 14000-14999 Slit absorbers/ Micro-perforated absorbers/ miscellaneous.
- 15000-15999 Examples of materials from the Material calculator.

Special materials

There are three special materials in the library. Special materials cannot be modified.

Material 0 (transparent)

Assigning Material 0 to a surface corresponds to removing the effect of the surface completely from all calculations. Therefore, surfaces with this material assigned:

- Offer no hindrance to rays, neither in energy or direction.
- Are excluded from the calculated active surface area of the room, and therefore do not affect the estimate of the room's volume produced by Global Estimate or Quick Estimate Reverberation.

This feature can be used to temporarily "remove" surfaces such as doors or reflectors from the room - or to define a phantom surface which has no effect on the room acoustics simulation but over which an energy map (a grid) can be plotted.

Material 1 (totally absorbing with ray termination)

The totally absorbent material, Material 1 can be used for modelling outdoor situations, e.g., an open roof. This is the only material which will stop the rays during ray tracing. No reflections will be generated from surfaces assigned this material. Using this material when some surfaces are known to be 100% absorbing can speed up calculations considerably.

Material 2 (totally reflecting)

Assigning Material 2 (totally reflecting material) on a surface makes it fully reflective. This is not a realistic material, as you should expect at least some absorption from any surface, but it can be useful to investigate a model and its limitations, as an extreme case.

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Material 3 (totally absorbing without ray termination)

Material 3 has an absorption coefficient of 1 at all frequency bands. The difference with Material 1 is that it does not terminate rays. The energy carried by the reflected ray depends on the surface's size and the angle of incidence. A non-negligible amount of energy can be reflected by relatively small surfaces at grazing incidence, such as an open window.

4.3 Editing/extending the Material library

You can edit the Material library in multiple ways. The following buttons will open a Material Editor with different functions to enter absorption data:

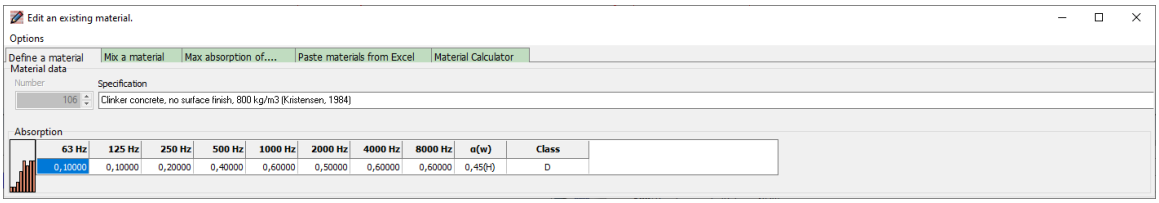
- Add material (Ctrl+M) copies the selected material in the Material library.
- Edit a Material (Ctrl+E) modifies the selected material in the Material library.

The material's specifications can be edited in the Material Editor. The material number cannot be modified, but if you create a new material, you can specify a number of your choice, provided that it is not already used in the library.

You can also edit the library file (.li8) in a text editor, where it is easier to make multiple changes to materials. Finally, materials can be deleted via the Delete button.

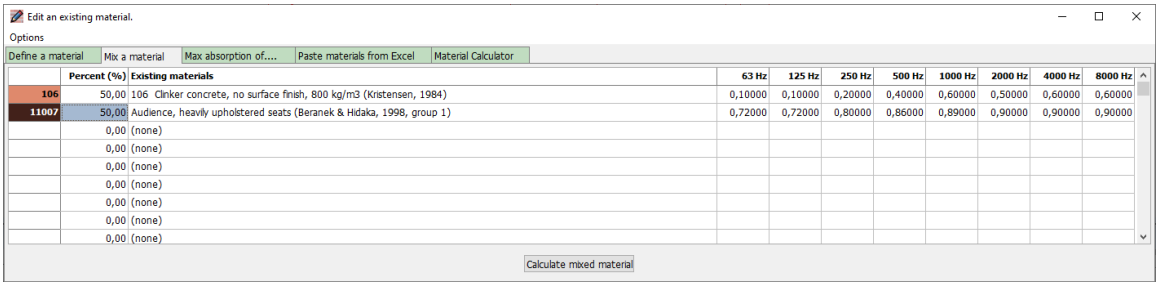
These options can be used both for the local and the global library. The changes will not be applied to the assigned materials in the Surface list (.mat file). Remember that material 0, 1 and 2 must remain as originally defined.

Define a material



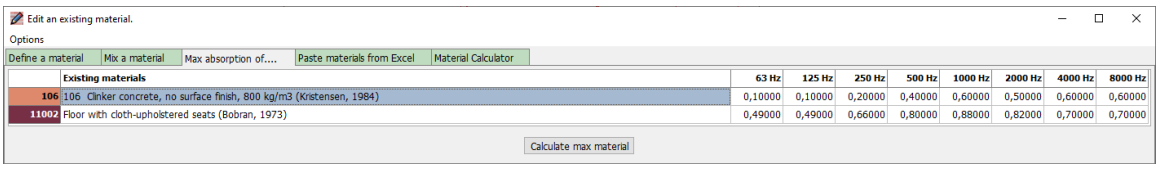
Enter the absorption coefficient directly per octave band in the table. The values should be between 0 and 1, or entered as percentage.

Mix materials



Create a new material by mixing several existing materials. This can be useful for surfaces which are composed of different materials.

Max absorption of…



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Create a new material by taking the largest absorption coefficient out of two materials in each octave band. This tool can help to model surfaces that present different absorption phenomena in different frequency ranges. For example, a carpet on a wooden floor would include high-frequency absorption due to the carpet and low-frequency absorption where the floor behaves as a membrane.

Paste materials from Excel (or similar software)

If you have data from a material manufacturer, they can be entered in our Excel template and imported into Odeon. Read more in Sec. 4.6.

Material calculator

Create new materials from a series of material layers and in specified mounting conditions. The Material calculator is explained more in detail in Sec. 4.5.

Modifying .li8 files

You can also modify the Material library in a text editor. The Edit Material library file button opens the .li8 file directly in the ODEON text editor. The data format in a .li8 file is very simple; each material is described by two lines:

ID_Number Descriptive_text
α63 α125 α250 α500 α1k α2k α4k α8K

ID_Number must be a unique number between 0 and 2.147.483.647.

Descriptive_text contains the material's specifications, as they appear in the table of the Material list.

The absorption coefficient α for each octave band should have a value between 0.00 and 1.00. If no data is available for upper or lower bands, we recommend using the value of the neighbouring band (e.g., use the value in the 4 kHz band for the 8 kHz band as well).

Caution! If the material is derived from the Material calculator, the message {Material Calculator. Do not edit manually!} is displayed in the descriptive text, and we recommend not to edit it. Otherwise, you might corrupt the file.
If materials have been imported via spreadsheet (e.g. manufacturer data), the data may include 1/3 octave absorption-, scattering-, diffusion-coefficients, as well as a number of other properties. The various data are separated by curly brackets {} and other control charters. Although the data can be edited manually, the format is fairly complex and we suggest editing the original data in the spreadsheet and reimporting the data from within Odeon if needed.

4.4 Editing the Surface list

The Surface list contains the material properties used in the ODEON simulation. In terms of absorption, most of the data comes from the Material library, but the absorption coefficients can also be edited in the Surface list.

Assign materials from the Material library

ODEON offers four functions to assign a material from the Material library to surfaces:

- **Assign material:** the selected material is assigned to the selected surface(s) in the Surface/Layer list (use Shift+Left mouse button to select several surfaces).
- **Global replacement:** the selected material is assigned to all surfaces that have the same material as the selected surface (not available in Layer mode).

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- **Global assign to layer:** the selected material is assigned to all surfaces belonging to the layer of the selected surface.
- **Assign material to all visible surfaces:** the selected material is assigned to all visible surfaces in the Surface list. If only some layers are displayed (as specified in the Set Layers menu), then the material is only assigned to the surfaces of the active layers.

Note: you can also assign a material by typing its number in the Material column.

Modify materials in the Surface list

Once materials have been assigned to surfaces, it is still possible to edit the absorption coefficient directly in the Surface list. Select a surface and edit the absorption table at the bottom of the list. Values can either be between 0 and 1 or entered in percent.

The modifications apply to all surfaces which have the same material as the selected surface and they are saved in the room's .mat file. However, these changes do not affect the Material library. This results in a mismatch between the material's properties in the Surface list and the Material library.

Note: as a general rule, the materials indicated in the Surface list correspond to the ones in the Material library. However, differences can occur between the two, when:

- The material has been edited in the Material library after the material was assigned to the surface.
- The absorption data of the material has been edited in the Surface List.
- The material was assigned on another computer, using another Material library with different material definitions.

This mismatch does not affect the project, as the relevant material data is saved with the room project (as a .mat file).

Click the ≠ button to check if materials in the Surface list corresponds to those in the Material library.

If you want to apply changes in the Material library to your project, remember to reassign the materials

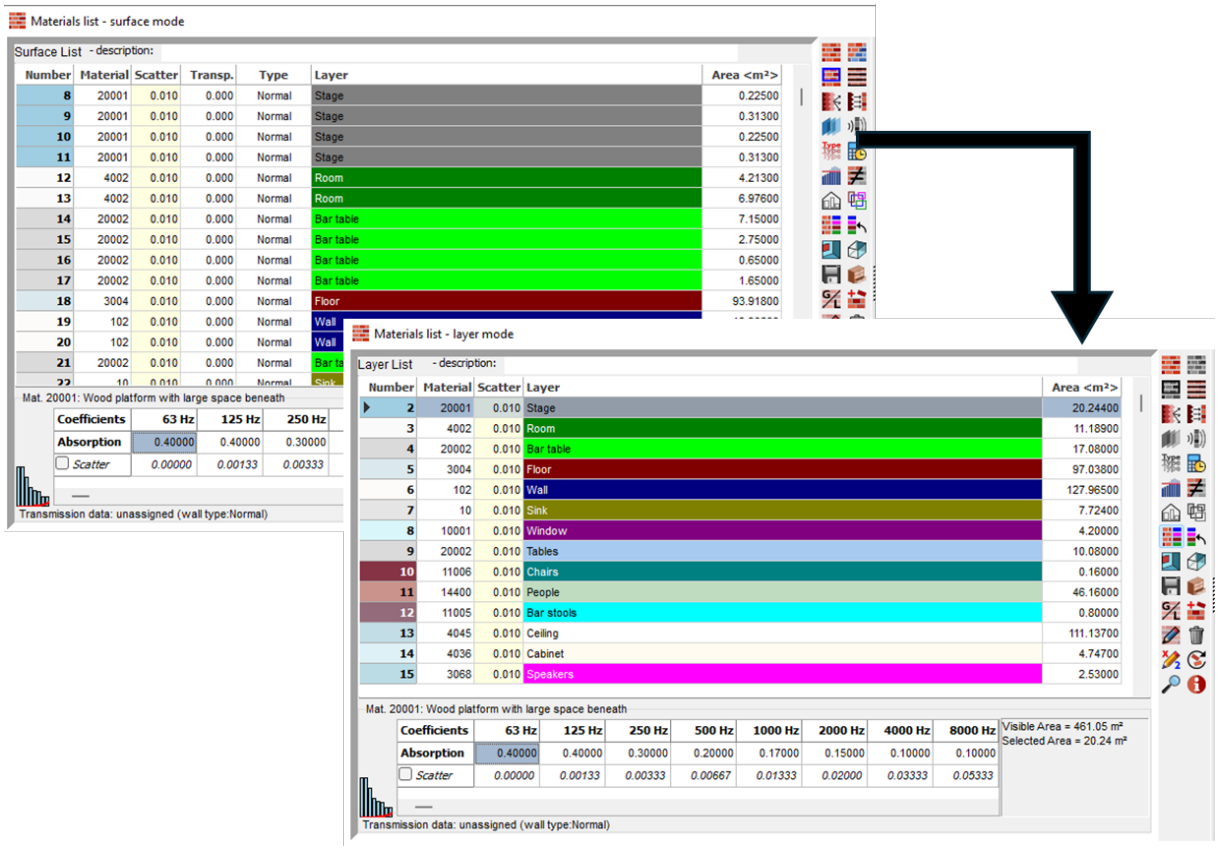
Other surface parameters

Surfaces are assigned other properties, including the Scattering coefficient, the Transparency coefficient, and the Wall Type. These properties are all independent of the absorption coefficient, so they are not linked to the Material library. Moreover, they are specific to a surface – not a material, as two surfaces with the same material can have different properties.

Layer mode

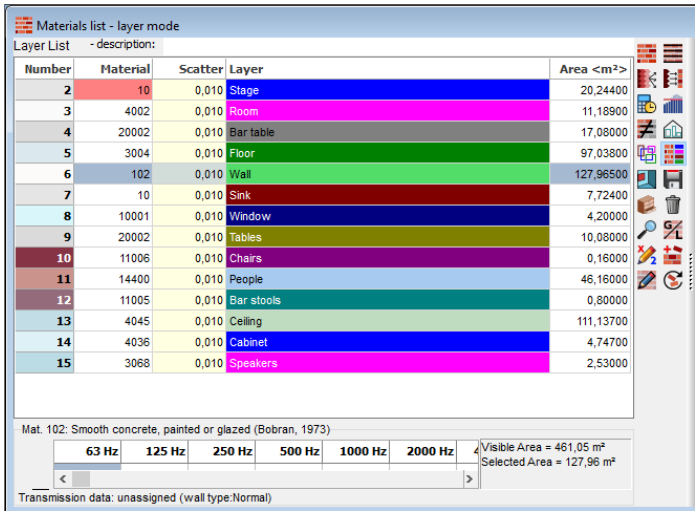
By pressing  , you can toggle between a Surface list (containing all surfaces in the model) and a Layer list (displaying the layers in the model). The layer mode is a useful tool if all surfaces belonging to each layer should be assigned the same material and the same scattering coefficient.

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Tip: layers can generally be defined in a 3D modelling program, such as SketchUp. The information is automatically imported in ODEON with the model.

Note: the transparency coefficient and the surface type are not included in the Layer mode. These settings can only be edited in Surface mode.



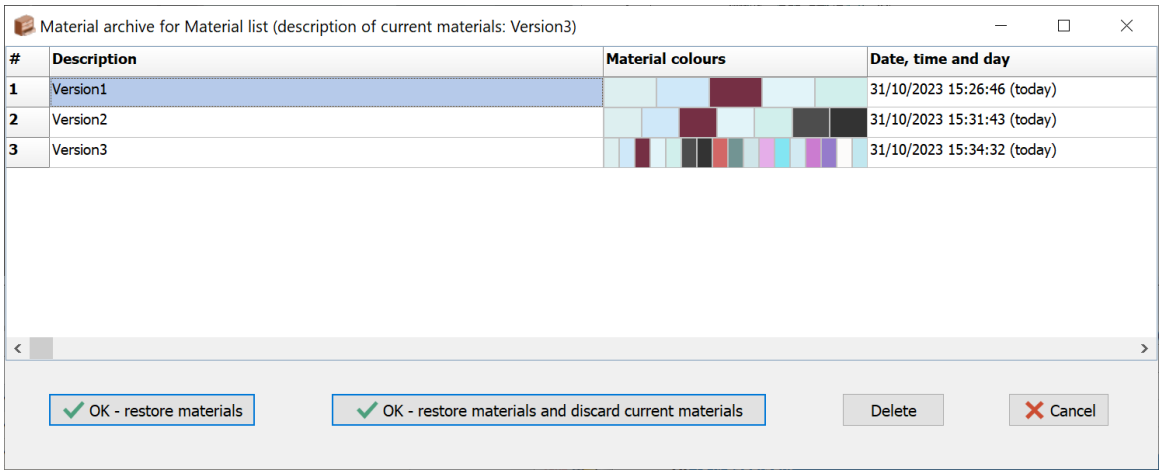
Surfaces from the same layer may have been assigned different materials and/or scattering coefficients in Surface mode. If this is the case, a warning message is displayed when toggling to Layer mode, and the mismatched data appears in red in the Layer List, as it shows for the Stage layer in the figure on the left. If a value is modified in Layer mode, the property will be overwritten for all surfaces belonging to the layer.

Material list archive

ODEON saves up to 10 previous versions of the Material list, which you can browse through using the Material list archive button . The Material colours column represent the materials used in each version. The colour stripes have an equal width, regardless of the area each material occupies in

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the model. The feature aims to help distinguishing the different versions visually – apart from their description - which might not be always meaningful, as it happens in the example below.



The archive can be useful to switch between different material configurations of the same room and keep track of the different versions. Typical usages are investigating the effect of different materials being assigned to the same surface, or studying the effect of adding/removing a wall in the geometry. For each version, you can update the description either directly in the Surface list or in the Material archive menu.

To save a current configuration, use the Save icon. Note that until you modify it, the current version does not appear in the Material archive.

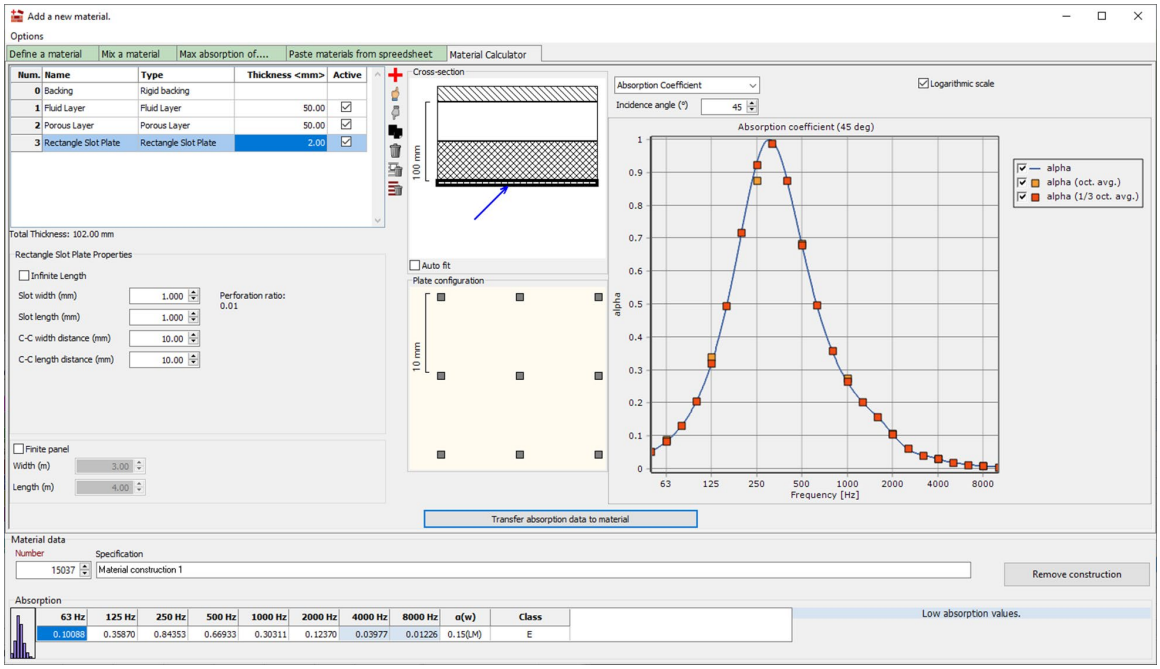
Caution! Only one set of simulation results is saved at a time, to keep it consistent with the material list. Therefore, changing the Material list version will delete any calculated results. If you want to keep the simulation results of different versions, use multiple copies of the room instead.

4.5 Material calculator

(Combined and Auditorium editions only)

With the Material calculator, you can create and customize constructions made from different material layers (e.g. perforated plates, porous layers or membranes). This tool can be useful for the design of absorbers, for instance by varying the geometry of a perforated plate or adjusting an air cavity behind a panel. It can also be considered a pedagogical tool to study absorption mechanisms in a given construction.

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Backing

The material construction includes a backing, which is the termination of the construction. It is selected in the first line of the table. Two options are available:

- If the construction is placed directly on a wall, choose **Rigid backing**.
- If the construction is not backed by a wall, choose **Air backing**.

Material layers

The Material calculator is based on the *transfer matrix method*, in which the material is represented by a transfer matrix, relating the pressure and the normal particle velocity on either side. The material is built as a stack of *material layers*, each represented by its own transfer matrix. The construction's transfer matrix is obtained as the product of the material layers' transfer matrices (Allard, et al., 2009).

Two different models are used, according to the material layer:

- **Equivalent fluid layers** are layers in which the sound propagation from one side to the other is effectively modelled. The transfer matrix of equivalent fluid layers has the following structure,

$$M_l = \begin{pmatrix} \cosh(\gamma \cos\theta\, h) & \frac{Z_C}{\cos\theta}\sinh(\gamma \cos\theta\, h) \\ \frac{\cos\theta}{Z_C}\sinh(\gamma \cos\theta\, h) & \cosh(\gamma \cos\theta\, h) \end{pmatrix},$$

  where h is the thickness, Z_C is the characteristic impedance and γ is the propagation constant. θ is the angle of propagation in the layer, and it is added to account for the angle dependence of the results.
- **Lumped layers** correspond to an additive impedance term. The lumped layers are characterized by a single quantity, which we call layer impedance Z_L. The transfer matrix is

$$M_l = \begin{pmatrix} 1 & Z_L \\ 0 & 1 \end{pmatrix}.$$

It represents the following relation between the sound field at the front and at the back of the layer,

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$$p_{front} = p_{back} + Z_L\, u_{back},$$
$$u_{front} = u_{back}.$$

In general, lumped layers cannot be placed directly in front of a rigid backing, for which $Z_{back} = \infty$, because in that case the calculation is invalid.
Each material layer contains a set of parameters, which can be edited below the table. The name, the layer type and the thickness can be changed in the table directly. We will now cover the different material layers available in the Material calculator.

Fluid layer

The fluid layer represents a lossless medium, with the following input parameters:

- **Medium density** (kg.m^{-3}),
- **Speed of sound** in the medium (m.s^{-1})

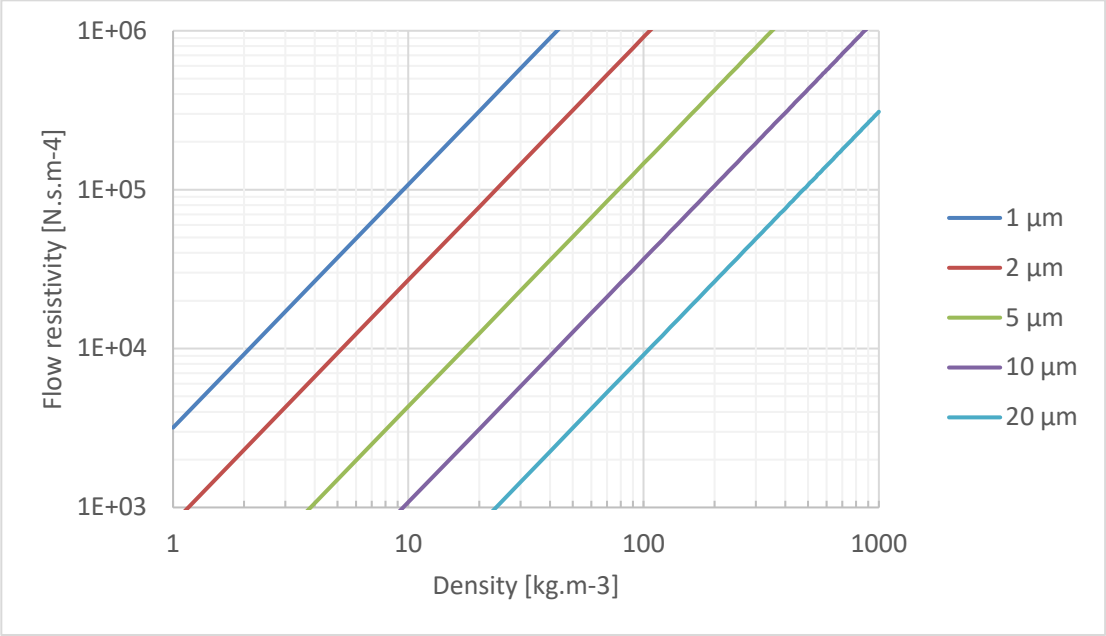
Pre-sets are available for air and water. The air pre-set is particularly useful to model cavities in the material construction.

Note: an air layer at the front or in the back of the construction does not change the absorption properties of the material. Therefore, using an air layer at either termination is not recommended. If you use an air backing, the first layer should not be an air layer.

Porous layer

Porous layers can be used to model porous materials such as mineral wool, foam, etc. They are equivalent fluid layers, which follow Miki's model (Miki, 1990). Miki's model is based on one input, which is the material's flow resistivity (N.s.m^{-4}).

Although the flow resistivity can be measured, it is not always available in a material's specifications. Nevertheless, you can find empirical models which relate the flow resistivity to other material properties. The example below can be used to characterize wool-like materials, and it relates the flow resistivity to the material's density and the diameter of its fibers (Bies, et al., 1980).



Fibrous materials: empirical relation between flow resistivity and density for different fibre diameters. From (Bies, et al., 1980).

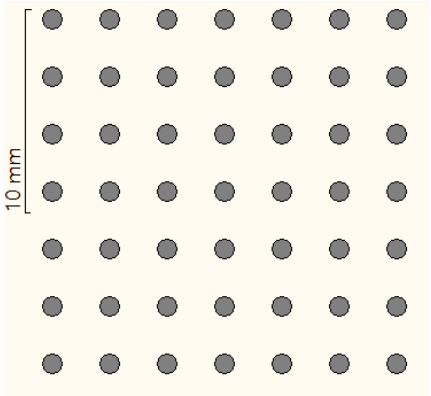
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The fibre diameters depend on the material. Typical values can be found in the literature (Christensen, et al., 1993):

- **Glass wool:** 1-8 μm;
- **Rock wool:** 2-5 μm;
- **Slag wool:** 2-5 μm.

Perforated plate

This category represents rigid plates with circular holes. We assume the holes are arranged as squares, as shown on the right figure.



The plate follows an equivalent fluid model from Johnson-Champoux-Allard (JCA) (Jaouen, et al., 2011). The input parameters of this model are the following:

- **Hole diameter** (mm).
- **Perforation ratio:** ratio between the hole area and the plate area, number between 0 and 1.

As sound is only transmitted through the holes, we do not include angle-dependence in the model. An end-correction is also added on both sides of the plate, in order to account for radiation effects at the outlets of the holes.

Some aspects to be aware of:

- The plate is assumed to be made of a perfectly reflective material, so it has no effect on the absorption properties. Similarly, bending is not included.
- The model only calculates absorption, not scattering. For small holes, we do not expect a too large scattering effect from the perforated plate.
- The perforation ratio is limited to $\frac{\pi}{4}$ (approximately 0.79), otherwise the holes overlap.
- The perforated plate model in ODEON is a low-frequency approximation, and it tends to underestimate the absorption at high frequencies. Therefore, in some cases, it might be needed to manually increase the absorption coefficient in the highest bands.

Perforated plate with rectangular holes

This material layer represents a plate with rectangular slots or infinite slits, following an equivalent fluid model by (Vigran, 2014). Just like the perforated plate, we disregard angle-dependence and we add an end-correction on either side of the plate.

The input parameters are the following:

- **Infinite length:** this makes it possible to choose between rectangle slots or infinitely long slits. When checked, the length parameters are deactivated.
- **Slot width/slot length**: slot dimensions (mm). The slot length is deactivated for infinite slits.
- **C-C width distance/ C-C length distance:** center-to-center distances between the holes (mm), in two dimensions. The C-C length distance is deactivated for infinite slits.

The perforation ratio is automatically calculated and it is displayed as a number between 0 and 1.

Some remarks:

- Like the perforated plate, we assume that the plate has no effect on absorption, and that it is made of a totally reflecting material.
- The model does not include scattering, only absorption.
- The slot dimensions must remain smaller than the respective C-C distances, otherwise the holes overlap.

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Membrane

The membrane type can be used to represent thin impervious sheets, such as plastic or rubber coverings, or plates such as a gypsum board. The model is based on a formula from (Rindel, 2018). It includes angle-dependence and the size of the plate. It is a lumped layer, so you cannot place it directly on top of a rigid backing.

The input parameters of the model are as follows:

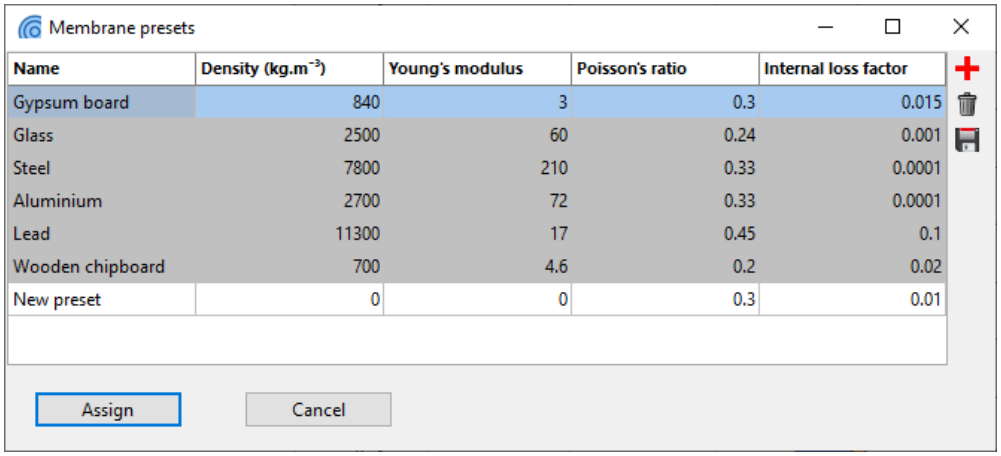
- **Density** (kg.m-3).
- **Young's modulus** (GPa).

Advanced parameters:

- **Poisson's ratio.**
- **Internal loss factor.**

In general, you don't need to change the advanced parameters – as they are set to their most common values.

In the membrane properties, the Load Presets button enables you to select typical materials for your membrane. The required material properties are then automatically loaded into the material calculator. ODEON comes with several suggestions (Rindel, 2018), but you can add your own by clicking on the + icon. ODEON materials are shown in grey and cannot be modified. Your custom materials can be saved in the list for future use, edited and deleted.



Note:

- Membranes cannot be placed directly in front of a rigid backing.
- When modelling a plate, we assume it has a rectangular shape, of the same dimensions as the entire panel (see next section). Therefore, the resonance of several smaller panels placed next to each other is not included in the model.

Panel dimensions

The dimensions of the panel can either be infinite or finite – assuming a rectangular size. Finite-sized samples include diffraction effects at the edge of the sample.

Note: for finite panels, we always assume that the material is surrounded by a rigid baffle. If *Air backing* is selected, this means that the construction is built on an aperture in the baffle, see below.

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Plotted results

On the right side of the calculator, the following quantities can be plotted in a graph:

- **Layer properties:** these depend on the model of the layer**.**
  - for equivalent fluid layers (fluid layer, porous layer, perforated plate, plate with rectangle slots): **characteristic impedance** and **propagation constant.**
  - for lumped layers (membrane): **layer impedance.**
- **Surface impedance** of the construction. We assume extended reaction so the surface impedance is angle-dependent.
- **Radiation impedance** of the panel. For an infinite panel, the radiation impedance is constant and equal to $\frac{1}{cos(\theta)}$, θ being the angle of incidence. Finite-sized panels are assumed to be rectangular, and the radiation impedance is calculated following (Davy, et al., 2014).
- **Reflection factor** of the construction. It is derived from the surface impedance and the radiation impedance as

$$R = \frac{Z_S - Z_R^*}{Z_S + Z_R}.$$

- **Angle-dependent absorption coefficient** of the construction, derived from the reflection factor,

$$\alpha = 1 - |R|^2 = \frac{4Re(Z_S)Re(Z_R)}{|Z_S + Z_R|^2}.$$

  The full-octave averaged values and the third-octave averaged values are also displayed.
- **Random absorption coefficient** of the construction. For finite-sized samples, the displayed absorption coefficient recreates the measurement conditions in a reverberation chamber (ISO 354, 2003), with the following formula,

$$\alpha_{random} = \int_0^{\frac{\pi}{2}} \frac{8Re(Z_S)}{|Z_S + Z_R|^2} \frac{Re(Z_R)^2}{|Z_R|^2} \sin(\theta)\, d\theta.$$

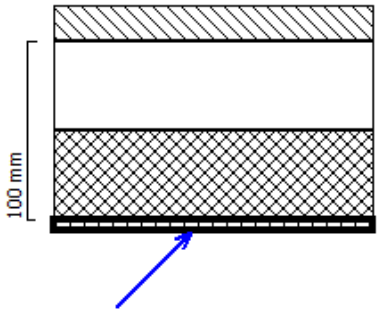
  This absorption coefficient can reach values larger than 1 (Rindel, et al., 2022). Both the full-octave averaged values and the third-octave averaged values are displayed. The **octave-averaged random absorption coefficient** is the one used by ODEON in calculations.

The complex quantities can either be displayed as a function of frequency or as a *Nyquist graph* (imaginary part as a function of real part). This is particularly helpful for the surface impedance and the reflection factor. The plot can be displayed both in *linear* and in *logarithmic* scales. All impedances are normalized to the impedance of air.

Incidence angle

The incidence angle can be varied for angle-dependent quantities (surface impedance, radiation impedance, reflection factor, oblique absorption coefficient).

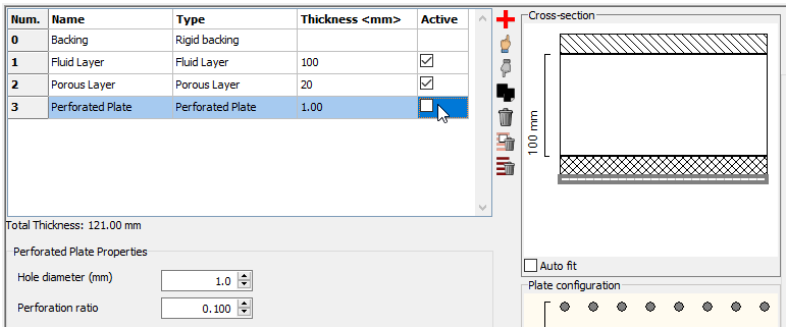
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Note: changing the incidence angle does not affect the random absorption coefficient, which assumes a diffuse field incidence.

Activate or deactivate material layers

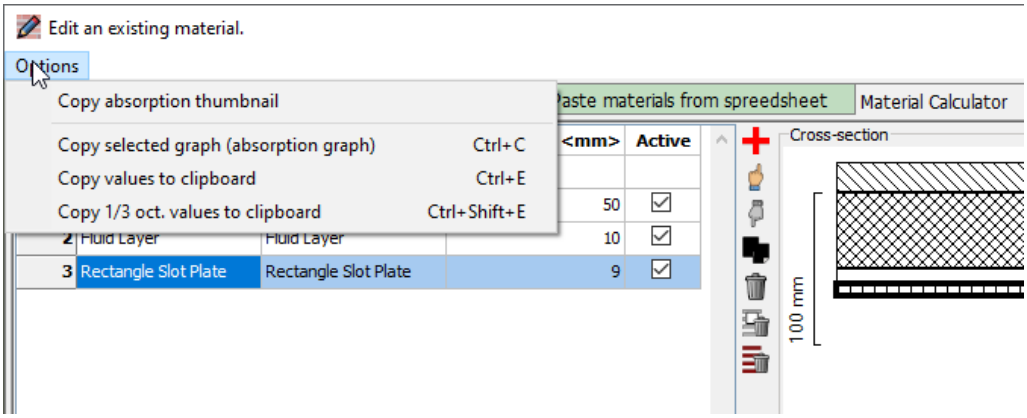
In ODEON 19, it is possible to activate or deactivate a material layer in a construction. This tool is useful to quickly compare how a specific layer influences the acoustic properties of a material. Simply click on the corresponding checkbox in the list of material layers.



When a layer is inactive, the displayed construction behaves exactly as if the layer was absent. This means that all rules on material layers apply. For instance, you cannot deactivate a layer if it leads to a lumped layer being directly on a rigid backing. This is why the checkbox is sometimes disabled. Inactive layers are greyed out in the cross-section drawing.

Exporting data

The following options are available to export data from the context-sensitive menu:



- **Copy absorption thumbnail:** copy the exported absorption coefficient in octave bands as an image. 

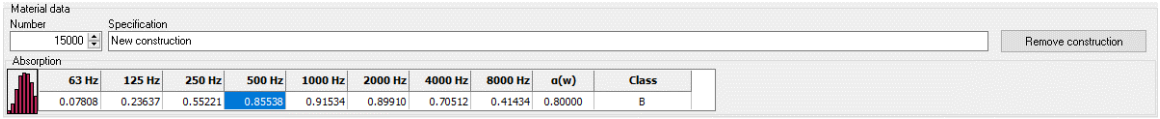
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- **Copy selected graph to clipboard (Ctrl+C):** copy the graph as displayed in the calculator.
- **Copy values to clipboard (Ctrl+E):** copy the values displayed in the right-side graph as a function of frequency.
- **Copy 1/3 octave values to clipboard (Ctrl+Shift+E):** copy the values in third-octaves.

Adding a material to the material list

Once the construction is ready to be used as a material in ODEON, click on Transfer absorption data to material. This will update the bottom part of the window: the absorption coefficient is filled in from the octave-averaged random absorption coefficient.

When transferring a material, all layers will be activated. If you want to save a material without the inactive layers, you should first delete them from your material construction.



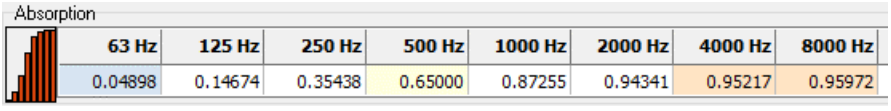
Although any sample size can be specified in the Material calculator, **we recommend using sufficiently large areas (above 10 m²) or even infinite samples** when transferring the absorption data to the material. Smaller samples will be assigned higher absorption because of edge diffraction. However, the reflection-based scattering algorithm of ODEON (see Chapter 9: Calculation Principles) will apply extra absorption to these surfaces during a simulation. Therefore, it is wise to avoid adding extra absorption due to edge diffraction twice, by using a sufficiently large area. A warning message is displayed if the material's area is smaller than 10 m². If the absorption coefficient is higher than 1, it is truncated to 1, following the methodology of (ISO 354, 2003).

A warning message is also displayed if some absorption values are extremely low (<0.01). Indeed, highly reflective surfaces may be unrealistic. This leaves you two options:

- **Overwrite the data:** absorption values below 0.01 are replaced by 0.01, in order to include at least some amount of absorption.
- **Keep the data:** the absorption values are kept as calculated, even the very low values.

In any case, you can freely change the values of the absorption coefficient after transferring the material, for instance if some of the values are known or if you want to ensure another minimum absorption coefficient.

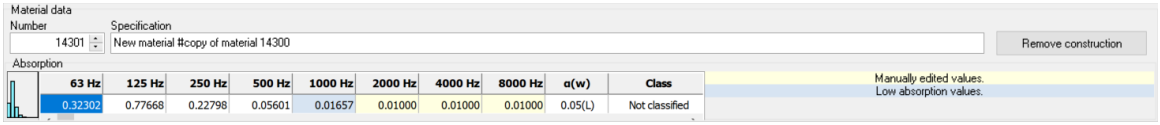
A series of indications are displayed in the absorption table of the Material editor.



- **Low absorption values:** indicates absorption coefficients below 0.05. Too reflective surfaces might be unrealistic because any surface absorb at least a fraction of acoustic energy.
- **High absorption values:** indicates absorption coefficients above 0.95. Too absorptive surfaces are also rarely found in real life.
- **Manually edited values:** indicates the absorption coefficients that differ from the calculated values in the Material calculator. This happens when you have modified the absorption coefficient after transferring the material, or if values have been truncated during the transfer ($\alpha > 1$ or $\alpha < 0.01$).

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You do not need to change the highlighted values; the warnings simply highlight potential issues in the designed absorber.



The button Remove construction on the right of the material name deletes the underlying model. You can use it if you want to keep the absorption coefficients without the calculator part.

4.6 Importing manufacturer data

ODEON provides an interface to easily import and visualise material data from manufacturers. The data can be imported via an Excel template available online. Useful information for ODEON includes the material's name, the absorption coefficient in octave or third-octave bands, as well as the scattering coefficient. The template can also include additional information that can help identify the material, such as pictures, link to data sheet, thickness, etc.

Material template in Excel

The Excel template can be found online and should be filled by manufacturers. Instructions to fill the template are also available on our website.

Mandatory data in the template includes:

- Company name,
- Product name,
- Absorption coefficient in octave bands from 125 Hz to 4 kHz.

Material data sheets can be found on our website.

Importing materials into ODEON

Check the validity of the data in the spreadsheet:

- The mandatory header should be present and properly filled in.
- The blue headers should not be modified for them to be recognized by ODEON.
- Octave band absorption coefficients should be values between 0 and 1.
- For backward compatibility with ODEON 18 and earlier, respect the order of columns A-R.

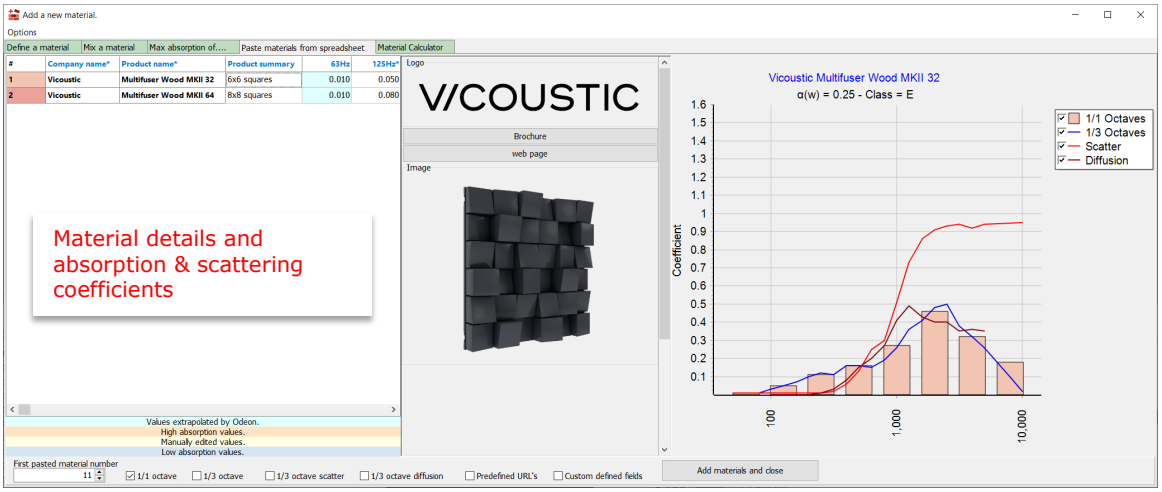
Select the rows you want to import, as well as the headers (row 5 in the template). Copy them to the clipboard by pressing Ctrl+C.

In ODEON, open the material editor and go to the "Paste materials from spreadsheet", press Ctrl+V.

Note: you can import multiple rows from the same Excel sheet directly.

The data will be displayed in the ODEON interface.

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The left side of the window is a table that lists the materials' properties. They can be edited at this stage. The cell colours can indicate low or high values for your coefficients. You can select which properties to display in the lower part of the window. At the centre, you will find optional additional information, such as pictures and links. The right part is a graph showing the different coefficients characterizing the material (absorption coefficient, scattering coefficient, diffusion coefficient).

Once you have inspected and/or corrected the data, pick a number in the lower part (First pasted material number) and click on Add materials and close. The materials will be added to your library, starting from the chosen number.

Material information

The material information menu is useful to display the data associated with a material. Note that this is a visualization tool, and the displayed data cannot be edited there.

For materials directly entered in ODEON, this corresponds mainly to the absorption coefficient, both in octave and 1/3 octave bands. If only octave band values were entered, third octave band values are interpolated. For imported materials, the menu displays all the information that was associated to it (coefficients, properties, images and links).

4.7 Scattering coefficient

While the *absorption coefficient* controls the amount of sound energy that is absorbed from a surface, the *scattering coefficient* determines the way sound energy is reflected. The basics will be explained below. For a deeper understanding of scattering coefficients, please refer to Section 9.5.

We can group reflections in rooms in three categories:

- *Specular reflections:* where the angle of reflection is equal to the angle of incidence.
- *Diffuse reflections:* where the angle of reflection is independent of the angle of incidence (memoryless reflection).
- A *mixture* of the cases above.

By default, ODEON uses a mixture, including a specular part and a diffuse part to sound reflections. Scattering is modelled in two ways in ODEON:

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- *Surface scattering*, which is quantified by a scattering coefficient, assigned to the surfaces in the Surface list.
- *Scattering due to diffraction*, which is included if Reflection Based Scattering is enabled in the Room Setup.

These two scattering processes are described more in detail in Chapter 9 (Calculation principles).

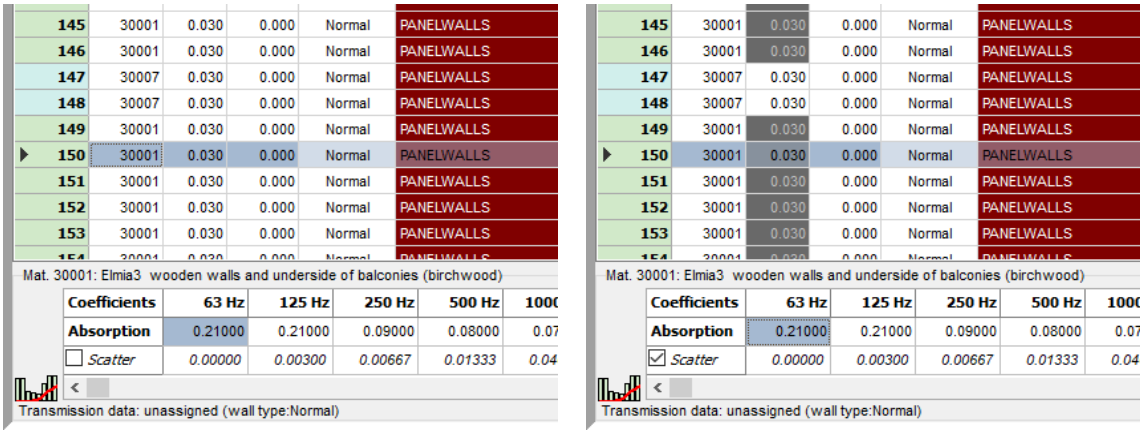
Note: You can deactivate Surface Scattering and Reflection Based Scattering in the Room setup, but this is only recommended for educational purposes and research.

As explained in Chapter 2, the room's geometrical model may need to be simplified for room acoustic simulations. In that sense, many fine details such as rough surfaces, objects placed on the walls, windows and crowds will be represented by flat surfaces in the ODEON model. A model of surface scattering is thus added to ODEON to account for scattering by these elements.
The scattering coefficient is a number between 0 and 1 which represents the ratio of non-specular reflected energy to the total reflected energy. It is a frequency dependent quantity but by default, ODEON uses a single number, which corresponds to the scattering coefficient at mid-frequencies (707 Hz). ODEON then expands the coefficient to appropriate values for the other frequency bands, using a typical behaviour of scattering in relation to frequency. This single value scattering coefficient is assigned to each surface in the Surface List.

Frequency-dependent *vs* single-number scattering

Since ODEON 19, You can decide to apply a frequency-dependent scattering coefficient profile to a material by activating the Scatter option in the lower-left table (*Surface list*). The chosen profile will be applied to all surfaces which are assigned this material. The corresponding single-number scattering coefficients in the surface list are greyed out to indicate that it is no longer in use.

Similarly, if an imported material containing a scattering profile is selected, it will be used for all surfaces which are assigned this material instead of a single-number value in the surface list.



Left: Scatter is unchecked, so the single value from the Surface List is used (0.030) independently for each surface. **Right:** Scatter is checked, the frequency-dependent values in the lower table are used for all surfaces with material 30001. The greyed-out cells in the Surface list indicates that the single value scattering coefficient is not used.

The benefit of using the frequency-dependent scattering coefficient per material is the immediate reusability of the same scattering profile across any surface assigned with that material. However, when specific surfaces have different geometrical characteristics while sharing the same absorption material (e.g. a smooth wooden surface versus the same wood applied to a wall with

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pyramid diffusers – simplified in ODEON), you can assign different scattering coefficients to each surface in order to properly represent the geometrical detail.

Note: Some acousticians call the scattering coefficient *diffusion coefficient*, but this is wrong. The *diffusion coefficient* of a surface describes the spatial uniformity of reflections from it, while the *scattering coefficient* determines the fraction of sound which is not reflected in the specular direction. A high scattering coefficient can lead to a high diffusion coefficient, but the two values are not directly linked. In addition, they are measured in two different ways (ISO 17497-1, 2004) and (ISO 17497-2, 2012).

Suggested values for the scattering coefficient

In ODEON, the default scattering coefficient is 0.01 (1 %), because real surfaces are never entirely smooth. A scattering coefficient of 1% is still on the low side, and it will still highlight potential acoustic problems such as flutter echoes. The reason to start with a value of just 1% is that we should first highlight these acoustic problems, and then actively choose to increase the scattering coefficient. When the scattering coefficient is left at its original value of 1%, it is highlighted in light yellow, indicating that you may consider putting your own value. A scattering coefficient of 0.02 – 0.05 for a smooth surface is generally a realistic value. The scattering coefficient should be higher for surfaces which have lost some level of detail in the geometrical model. Even a few rough objects sparsely placed on a surface greatly increase the scattering properties of the surface.

The scattering coefficient (at the mid-frequency 707 Hz) that should be used for various materials is an ongoing research area. Our current recommendations for real structures are the following:

Material	Scattering coefficient at mid-frequency (707 Hz)
Audience area	0.6–0.7
Rough building structures, 0.3–0.5 m deep	0.4–0.5
Coffered ceiling	0.3-0.4
Bookshelf, with some books	0.3
Normal smooth surfaces	0.01 (default value)
Highly smooth painted concrete	up to 0.01

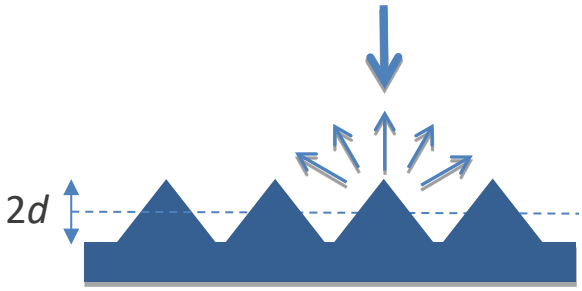
Suggested scattering coefficients to use for various materials. The given values are to be assigned to surfaces in ODEON and correspond to the middle frequencies at 707 Hz. Suggestions may be subject to changes as more knowledge on the subject is achieved.

With the suggested scattering coefficients, it is assumed that Reflection based scatter has been enabled in the Room setup, in which case ODEON will account for effects such as distance, angle of incidence and edge diffraction (read Chapter 9 about Calculation Principles for more information). If Reflection based scatter is disabled, then it is recommended to increase the scattering coefficient further (default scattering coefficient to 0.1; 0.3 may be more appropriate for disproportionate rooms such as class rooms).

Example: diffuser with pyramidal wedges

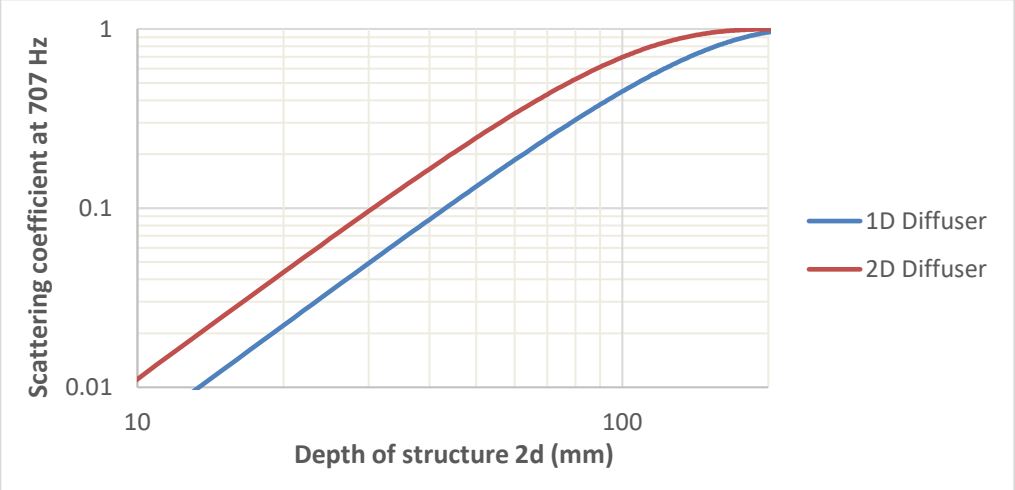
The example below can serve as a rule of thumb to estimate the scattering coefficient of a rough surface, following a theoretical model based on (Rindel, 2015). We consider a surface with a cross-section as shown in the figure below. The surface has a pyramidal structure which should be represented as a flat surface in the simulation model. Scattering will then be accounted for by assigning a scattering coefficient to the surface.

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A diffuser with a *depth of structure* equal to $2d$. This type of structure is simplified in ODEON by modelling it as a plane surface and assigning scattering coefficient according to the frequency functions described below.

The scattering coefficient of the surface depends on the depth of structure $2d$, the graph below illustrates this dependence according to a theoretical model (Rindel, 2015). For example, for a 1D diffuser of depth $2d$ = 15 mm, the scattering coefficient is approximately 0.01 (1 %) – which corresponds to the default value in ODEON.



Scattering coefficient of a surface with a pyramidal diffuser according to the depth of structure $2d$ **(Rindel, 2015)**.

As a first approximation, the scattering coefficient of an arbitrary rough surface can be read from this graph by using an average depth of structure. However, you should remember that this is based on a theoretical model and a specific roughness profile, so the actual scattering coefficient might differ.

4.8 Transparency coefficient – semi-transparent surfaces

A transparency coefficient can be assigned to each surface; this is a way to make the surface semi-transparent. This feature may be used when modelling many small surfaces grouped together, in a simplified manner. For instance, a reflector panel built from many small surfaces with space in-between or an installation ceiling can be modelled as one large surface having a transparency coefficient of, e.g. 0.5. The transparency coefficient can be assigned values between 0 and 1:

- 0.0 is the default value assigned to all solid walls. This value should always be assigned to the boundary walls of the room; otherwise, rays will escape from the model.

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- Very small transparency coefficients should be avoided unless the number of rays is increased substantially. Instead, consider modelling the surface as solid. Using a transparency coefficient larger than zero will cause the Image source method to be discarded for rays hitting such surfaces (only relevant for point sources). Another problem is that only very few rays will be transmitted, making the results on the other side of the surface statistically unreliable.

- Very large transparency coefficients, e.g., 0.95 should also be avoided. Instead consider removing the surface from the model, or more easily, assign Material 0 (transparent) to the surface.

Remember: If entering scattering and transparency coefficients between 1 and 100, ODEON will assume that the values are in percent and divide values by 100.

The Transparency value should not be used for modelling sound transmission through walls - instead you should use the Transmission wall type for this purpose as explained below.

4.9 Different Wall Types

The wall type controls what happens when a sound ray hits a surface in ODEON.

There are four different wall types in ODEON. The Normal, Exterior and Fractional types relate to the way Reflection Based Scattering is calculated for sound reflecting from the surfaces.

- Normal is the default value. It results in default handling of scattering and diffraction taking the Reflection Based Scattering method into account if it is enabled in the Room setup.
- Exterior forces a surface to be handled as an exterior surface even if it was not detected as such by ODEON. The result is that less diffraction is applied at the lowest frequencies where offset in the wall is not sufficient to result in low frequency diffraction.
- Fractional should be used for surfaces which are fractions of a bigger whole. This could be surfaces being part of a curved wall or a dome. These surfaces should not cause diffraction due to their individual area, and therefore the individual surfaces do not provide any significant edge diffraction.
  When setting the type to Fractional, the surface area used for calculating the Reflection Based Scattering Coefficient is determined from the box subscribing the room. If the construction part which the fractional surface is part of is considerably smaller that the 'room box', the scattering might be underestimated and a higher scattering coefficient should be assigned to the surface. From ODEON 18, you do not need to use the Fractional type for surfaces belonging to the same plane, because ODEON will cluster them automatically.
- Transmission is for walls which transmit sound to another room. When this wall type has been selected, it is possible to edit the transmission data to specify the reduction index (transmission loss). It is also possible to link the wall with another surface in case the wall is composed of two distinct parallel surfaces, and possibly with different surface materials on either side.
  When the Transmission type is assigned to a surface, 90% of the rays hitting the surface will be reflected and 10% will be transmitted. The energy calculations are accomplished by multiplying each ray (or particle) with the appropriate frequency dependent energy parameters. Transmission is covered in Appendix B: Specify Transmission Though Walls.

4.10 Material Toolbar

Below is a guide to the Material List Toolbar. The letters **S** and **L** in the fourth column indicate if the tool is available in the Surface or Layer mode respectively (or both of them for most of the tools).

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Remember that the scattering coefficient, transparency or wall type of a surface needs first to be entered in the Surface list in the appropriate cell using the keyboard or mouse.

	Assign Material	Ins	**S & L**	Assigns the material selected in the Material list to the selected row(s).
	Global Replacement	Ctrl+G	**S**	Replaces all instances of a material in the Surface list.
	Global Assign to Layer		**S**	Assigns the selected material to all surfaces on the selected layer.
	Assign Material to all visible surfaces	Ctrl+Ins	**S & L**	Assigns the material selected in the Material list to all rows.
	Repeat last entered scattering coefficient for selected surface(s)	Alt+S	**S & L**	Assigns the last entered scattering coefficient to the currently selected row(s).
	Assign Scattering Coefficient to All Surfaces		**S & L**	Assigns the scattering coefficient of the currently selected row to all row(s).
	Repeat Transparency Coefficient for Selected Surface(s)	Alt+T	**S**	Assigns the last entered transparency coefficient to the current selected row(s).
	Edit Transmission data	Alt+Y	**S**	Opens the Transmission menu. The button is only active if the surface type is Transmission.
	Repeat last entered wall type	Ctrl+Y	**S**	Assigns the last chosen wall type to the currently selected row(s).
	Quick Estimate	Ctrl+Q	**S & L**	For a fast evaluation of reverberation times and a summary of absorption areas. Not as accurate as a full simulation, but useful for quickly experimenting with different configurations before running a lengthier simulation.
	Limit absorption coefficient		**S & L**	Specify a minimum and a maximum absorption coefficient for the materials in the surface/layer list. This is useful because extreme values in the absorption coefficients can have an extreme effect on results (Oppenheim, et al., 1989).
	Check agreement		**S & L**	Compares the materials specified in the Surface/layer list and those defined in the Material library. Indicates which materials have a different definition, if any.
	Toggle interior/exterior	Ctrl+T	**S & L**	Cycles between showing interior surfaces, exterior surfaces, and both.
	Set layers	Ctrl+L	**S & L**	Enables or disables layers from showing up in the Surface list and in the model.
	Toggle surface/layer mode	Alt+L	**S & L**	Switches between Surface mode (where surfaces can be modified individually) and Layer mode (where you can edit all surfaces of the same layer at once).
	Reassign materials by layer		**S & L**	Reassigns materials in a CAD model that was reimported (from another software than SketchUp).
	Toggle layer/material colours	Ctrl +Shift +O	**S & L**	In 3D Render view, either displays the surface colours by layer or by material properties.

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	Toggle 3D View/3D Render	Ctrl+V	**S & L**	Toggles between the legacy 3D wireframe view and the 3D Render view.
	Save materials			Saves the material configuration without closing the Material list.
	Material list archive	Alt+R	**S & L**	Opens the Material list archive; you can choose from up to 10 last versions of the Surface list.
	Toggle between Global and Local room Library		**S & L**	Switches between the Global material library and the Local room material library.
	Add material(s)	Ctrl+M	**S & L**	Opens the material editor to insert a new material. The new material is the copy of the currently selected one in the Material library.
	Edit a material	Ctrl+E	**S & L**	Opens the material editor to edit the currently selected material.
	Delete Material	Ctrl+Del	**S & L**	Deletes the selected material from the Material library.
	Edit Material Library File		**S & L**	Opens the Material library file in the ODEON text editor.
	Reload Material Library	Ctrl+R	**S & L**	Loads changes to the Material library file that were made in the text editor.
	Search for Surface or Material with name…	F3	**S & L**	Enables a search field in the Surface/Layer list or the Material library.
	Display material information	Ctrl+I	**S & L**	Displays additional information (1/3 octave values, images and other material properties) for the currently selected material.

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5 Calculation results

This chapter covers the different calculation types available and the results they provide. To learn in more detail about acoustic parameters and decay curves, please read Chapter 8 and for the theory behind Odeon calculations read Chapter 9.
The software is made in such a way that you can easily calculate the most common results, making it easy to get started as a new user. Using the available options from the *context-sensitive* menus and keyboard shortcuts, you have access to more advanced displays covering a broad range of results.

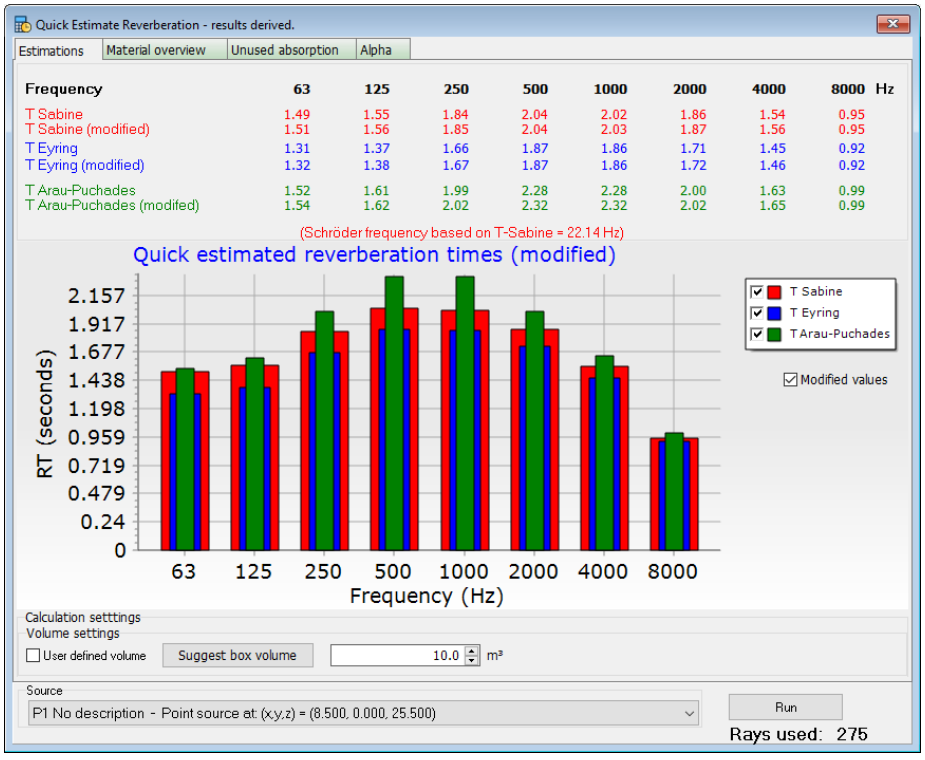
Remember: As Described in the Quick Start Guide, the menu between Toolbar and Options always gets updated with the active Window or the active tab-sheet in that window inside ODEON. Click that *context-sensitive* menu to retrieve all possible functions and Shortcuts for the corresponding Window. Always press F1 when you need to learn more about specific functions in ODEON. The context sensitive help will open the page related to the active window. The ODEON help file complements the manual and offers extra information.

5.1 Global Calculations

Global calculations in ODEON are the ones that do not depend on receiver positions. They still use a source, but results refer to the room as a whole. The acoustic parameters calculated are limited to reverberation parameters RT (reverberation time based on analytical formulas) or T_{20} and T_{30}.

Quick Estimate

Quick Estimate is a fast calculation of reverberation time which is found in the Material List. It is based on analytical formulas like Sabine's and Eyring's, which do not take into account the actual geometry and position of materials in the room, but only the *amount of absorption* and *volume*.



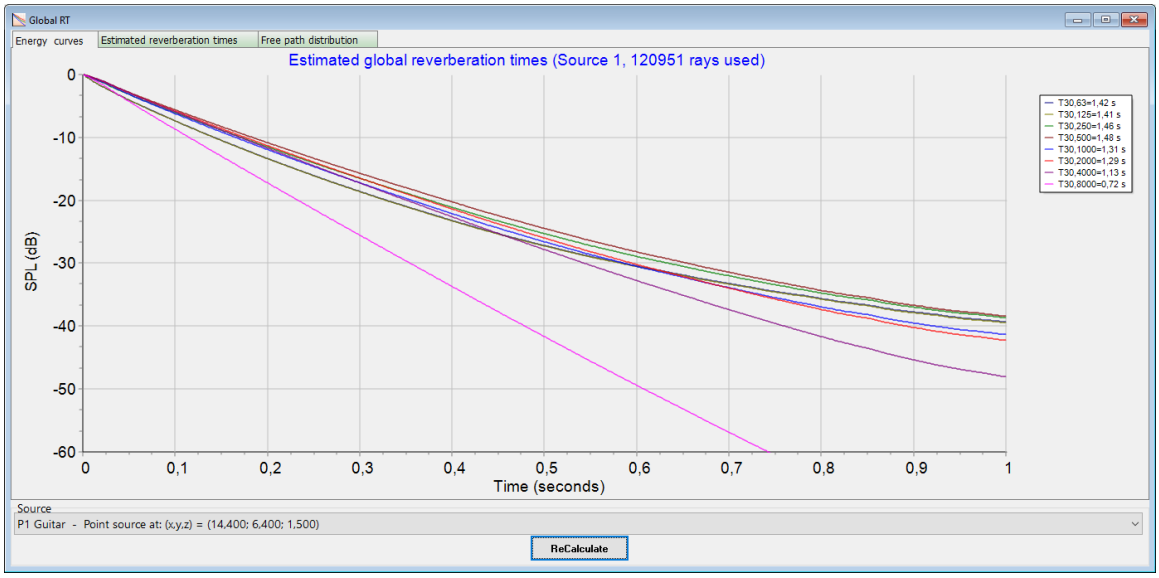
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The tool can be used for a fast overview of acoustics in a room, while assigning materials. Several informative tab-sheets are available:

- Estimations provides fast estimation of RT based on analytical formulas, excluding the actual the geometry. The estimated reverberation time is a good starting point to define the impulse response length in the Room Setup. A good rule of thumb is to set the impulse response length 2/3 of the maximum reverberation time in the Quick Estimate.
- Material Overview offers an overview of used materials; with the corresponding absorption areas they occupy.
- Unused absorption shows which surfaces/materials have a lot of unused absorption to offer.
- Alpha shows all the absorption coefficient curves for the different materials used in the room in one graph which can be used for a quick comparison or for inclusion in a report.

Global Estimate

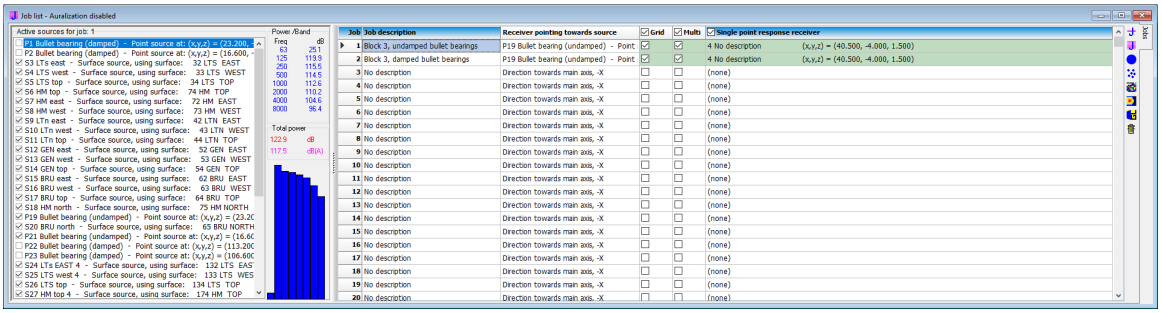
The Global Estimate is found in the top toolbar. It makes use of ray tracing in order to calculate the overall/global reverberation time in the room. The tool is much more accurate than the Quick Estimate and it depends on the selected source at the bottom drop down menu. The calculation is receiver-independent, giving an average result for the whole room volume, while in reality there will be some local variation though normally the reverberation time is fairly constant for a room.



5.2 Point response calculations

A point response calculation gives the response of the room for a particular receiver position (with a given receiver orientation). The point response is generated as a response to one or multiple sources emitting a Dirac delta function at the same time (each source can be assigned an individual delay). ODEON simulates the impulse response between the source(s) selected and each receiver, out of which all Room Acoustic Parameters are calculated (see Chapter 8). Point responses are managed from the Job List window which can be populated by up to 1000 jobs.
For each Job, the desired active sources can be selected from the available sources in the pane on the left side of the Job List (or upper side if the Job List window size is small). Please check the *Quick Start Guide* for an overview of the Job List, with examples of use.

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Grid Responses (I)(A)(C)

Room Acoustic Parameters (see Chapter 8) will be calculated for the surfaces selected in the Define Grid in form of colour maps. For an overview on defining grids see Chapter 6. To calculate a defined grid, make sure to tick both the Grid checkmark on top of the column, as well as the checkmark for a particular Job. Click the Run Job button to run the job. Once the calculation is finished, the job turns *green*.

To see a calculated Grid Response, click the calculated desired Job then click the View Grid Response button (shortcut Alt+G).

Multi Point Reponses (B)(I)(A)(C)

Room Acoustic Parameters (see Chapter 8) will be calculated for ALL receivers defined in the Source Receiver list. This allows to see all parameters for each receiver, statistics for a selected number of receivers, to compare simulated versus measured parameters etc. After point responses have been calculated for all receivers, it is possible to create groups of receivers allowing results, statistics etc. to be displayed for a subset of the calculated receivers. To calculate a Multi-point response, make sure to tick both the Multi checkmark on top of the column, as well as the checkmark for a particular Job. Click the Run Job button to run the job. Once calculation is finished, the job turns *green*.

To see a calculated Multi-point Response, click the calculated desired Job and then click the View Multi point response button (shortcut Alt+M).

Available Results in the Multi Point Response

Here is a short overview of the available tab-sheets in the Multi Point Response. To navigate the results, check the functions in the *context-sensitive* menu bar. If needed, use the help file for additional info. Find the help file by pressing F1 when the display of interest is selected (context sensitive).

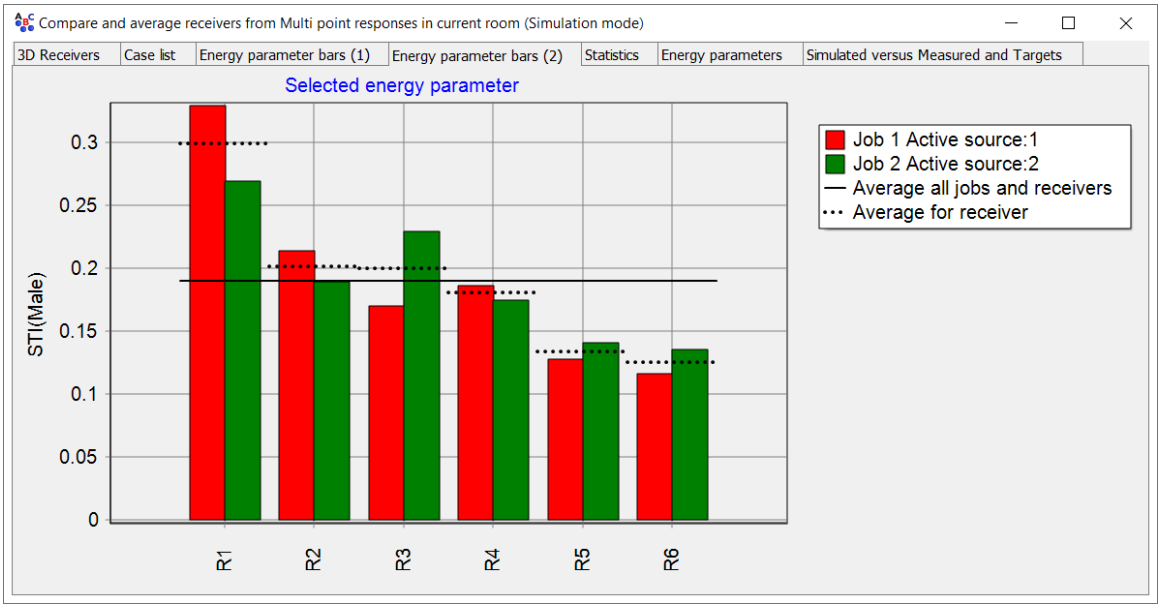
- 3D Sources and Receivers displays the sound sources and the receiver currently active. On the right side of the tabsheet you can select groups of receivers, specify which receivers should be active in the selected group and save the selected group for later use (remember to do so). The result displayed in the multi point response display will be for the receivers currently active. If only one receiver is active then some of the tab-sheets listed below will not be displayed.
- Energy parameters displays the calculated acoustic parameters in table format. The parameters could be EDT, T_{20}, C_{80} and etc. The parameters can easily be selected and copy-pasted into e.g. EXCEL if you are interested in making graphs or statistics outside ODEON.
- Energy Parameter bars (1) displays the calculated acoustic parameters as bars graphs as a function of frequency (octave bands). The parameters could be EDT, SPL, C_{80} and etc. Use the arrow keys to navigate between parameters and the R shortcut to change Receiver.
- Energy Parameter bars (2) displays calculated room acoustic broadband parameters. The horizontal axis displays the receivers.
- Parameters versus distance displays parameters as a function of distance, by having the receivers lined up from the nearest to the one furthest away (from the source).
- Statistics displays statistical calculations of parameters for the selected receivers, e.g. Average, Standard deviation, Min/Max values.

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- Spatial decay curve displays parameters based on ISO 3382-3, for open plan offices, but only if the simulation setup is according to the standard. See application notes *ISO 3382-3 Open Plan offices - part 1 and 2* about using the standard in ODEON: https://odeon.dk/learn/application-notes/.
- STI versus distance also displays parameters based on ISO 3382-3, parameters for open plan offices, but only if the simulation setup is according to the standard.
- See application notes as above.
- Measured versus Simulated display measurements and simulation results for the same room if you have imported measured results. This is a very useful tabsheet that allow making sure that a model matches well to reality in acoustical renovation projects or to verify your work after a simulated room has been built.

Compare and average multi-point responses

This tool provides graphs and data to compare multi-point responses, from the same project or even from different projects. Statistics such as averages and standard deviations can also be obtained.



What to use the comparison tool for

Below are some scenarios where you might want to compare and/or average different multi-point responses.

Within the same room:

- Study the influence of the source position on typical room acoustic parameters.
- Average room acoustic parameters with multiple source positions, as recommended by international standards such as ISO 3382.

From different rooms/projects:

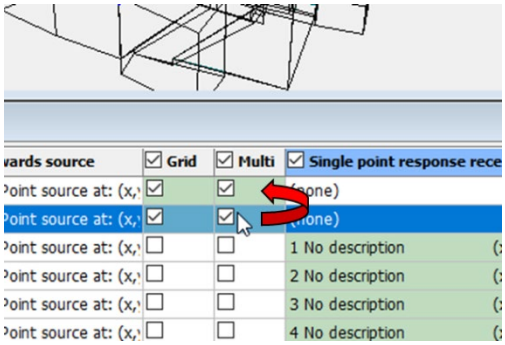
- Showcase the effect of a modified construction (e.g., wall, panel, separator) on the room acoustic parameters.
- Compare the influence of different material configurations on the room acoustic parameters, using the material archive. Read more about the material archive in Section 4.4.
- Compare fundamentally different rooms, for instance to show how the acoustics can change in very different spaces.

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How to access the tool

In the Job list, the button will let you compare all available multi-point responses in the current room.

Alternatively, you can drag and drop one multi-point response into another:



- **Compare two jobs from the same project:** drag-and-drop a multi-point response from the job list into another one.
- **Compare two jobs from different projects:** open the projects in two different instances of ODEON. Drag-and-drop the multi-point response from the first project into the one from the second project.
- **Add a job to an already existing comparison:** drag-and-drop the multi-point response into the comparison window. Note: the multi-point response can come from the same project or a different one.

Available results

The available tabs and results depend on whether the multi-point responses all come from the same ODEON project or different ones. The display is quite similar to the Multi-Point Response menu.

- Case list shows which multi-point responses are compared, displaying information on the jobs themselves (job number and description, active source(s)) and the room (room name, materials from the material archive). This is also where you can edit the name of each job, as displayed in the legend of the graphs. Finally, you can activate/deactivate jobs to show/hide them from the results.
- Energy parameter bars (1) displays the frequency-dependent room acoustic parameters as bar graphs. The horizontal axis corresponds to the octave bands. Horizontal black lines show the average across all jobs for each octave band.
- Energy parameter bars (2) displays the broadband parameters. This time, the horizontal axis corresponds to the receivers. If the jobs come from different Odeon projects, only the average across all receivers is displayed.
- Receiver statistics shows the standard deviation, average minimum and maximum values for each frequency, per parameter.
- Energy parameters contains all the comparison and statistics data in a text format. The data can easily be copied and pasted in an external document, such as a spreadsheet or a text file.

If all selected jobs come from the same ODEON project, they rely on the same set of receivers, so more receiver-dependent options become available:

- 3D Receivers: same interface as in the multi-point response. A 3D view of the room shows the receiver locations, and you can define groups of receivers.
- Energy parameter bars (1): the graphs are displayed per receiver. Use R/Shift+R to change receivers.
- Energy parameter bars (2): the results are presented by receiver (as displayed on the horizontal axis). The dashed black lines represent averages per receiver and the continuous black line is the average across all jobs and receivers.
- Energy parameters: if all jobs come from the same room, the results can also be ordered by receiver. Click on Pf(R,J) or Pb(R,J) to access them directly.
- Simulated versus measured and Targets displays measurements and simulation results for the *same* room if you have imported measured results into some of the multi point responses. This is a very useful tabsheet to verify that a model matches well to reality, in acoustical renovation projects or after a simulated room has been built.

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Note: if every job only has one active source and the source number is equal to the job number (e.g. Source 1 active in Job 1, Source 2 active in Job 2 and so on), then the point responses will be listed as source-receiver pairs (S1R1, S1R2, S2R1, S2R2, etc.). Otherwise, they will be listed by jobs: J1R1, JS1R2, J2R1, J2R2, etc.

Single Point Responses (A)(C)

In contrast to the Multi Point response, the Single Point response derives the impulse response and Room Acoustic Parameters for one receiver only. The Single Point response allows for more detailed results, graphs and curves, as well as for auralisation at the receiver position (see Chapter 7). To calculate a Single Point response, make sure to tick the Single Point Response Receiver checkmark on top of the column, as well as to select a Single Point response receiver from the drop-down list in the Job List. Click the Run Job button to run the job. Once calculation has finished, the job cell turns *green*.
To see a calculated Single Point Response, click the calculated desired Job and then click the View Single Point Response button (shortcut Alt+P).

Available Results in the Single Point Response

Here is a short overview of the available tab-sheets in the Single Point Response. To navigate the results, check the functions in the *context-sensitive* menu bar. If needed, use the help file for additional info. Find the help file by pressing F1 when the Single Point Response is open (context sensitive).

- Parameter bars display the calculated acoustic parameters in bars graphs as a function of frequency (octave bands). Parameters could be EDT, SPL, C80 etc. Use the arrow keys to navigate within different parameters.
- Energy parameters display the calculated acoustic parameters in table format. Parameters could be EDT, T_{20}, C_{80} and many more. It is easy to select, copy and pasted the parameters into e.g. EXCEL if you are interested in making graphs or statistics outside ODEON.
- Decay curves display the decay curves for each frequency band. Read about decay curves in Chapter 8.
- Decay Roses display how much sound energy is received at cumulative time intervals in the horizontal and vertical planes. This can give an idea of how different parts in the decay are formed throughout time.
- Reflection density displays how many reflections arrive at the receiver position per millisecond as a function of time. The graph can be used for judging if enough rays have been used in the simulation. A rule of thumb is to have at least 50 reflections per millisecond.
- Reflectogram displays the arrival times and strength of Early Reflections arriving at the receiver. Time starts counting (0 sec) from the moment the direct sound arrives at the receiver.
- 3D Reflection paths/Active sources visualises the reflection paths corresponding to the reflections in the Reflectogram. Use the options from the context-sensitive 3D Reflection Paths menu to exhaust all the possibilities of the tab-sheet.
- BRIR shows the Binaural Room Impulse Response. Only available if activated in the Auralisation setup (Chapter 7). The impulse response is filtered for left and right ear, according to the HRTF (head-related transfer function) and Headphone filter used.
- Dynamic diffusivity curves is a specialized research tool for diffusivity. Use the help file (F1) for a thorough explanation.
- Dietsch echo curves is a tool which helps investigating noticeable echoes. Use the help file (F1) for a thorough explanation.

Auralisation (A)(C)

Auralisation which makes use of the simulated impulse responses and combines them with anechoic (dry) wave files, providing a realistic listening experience at the receiver position are closely related to the Single Point response. In simple words, auralisation gives you the ability to

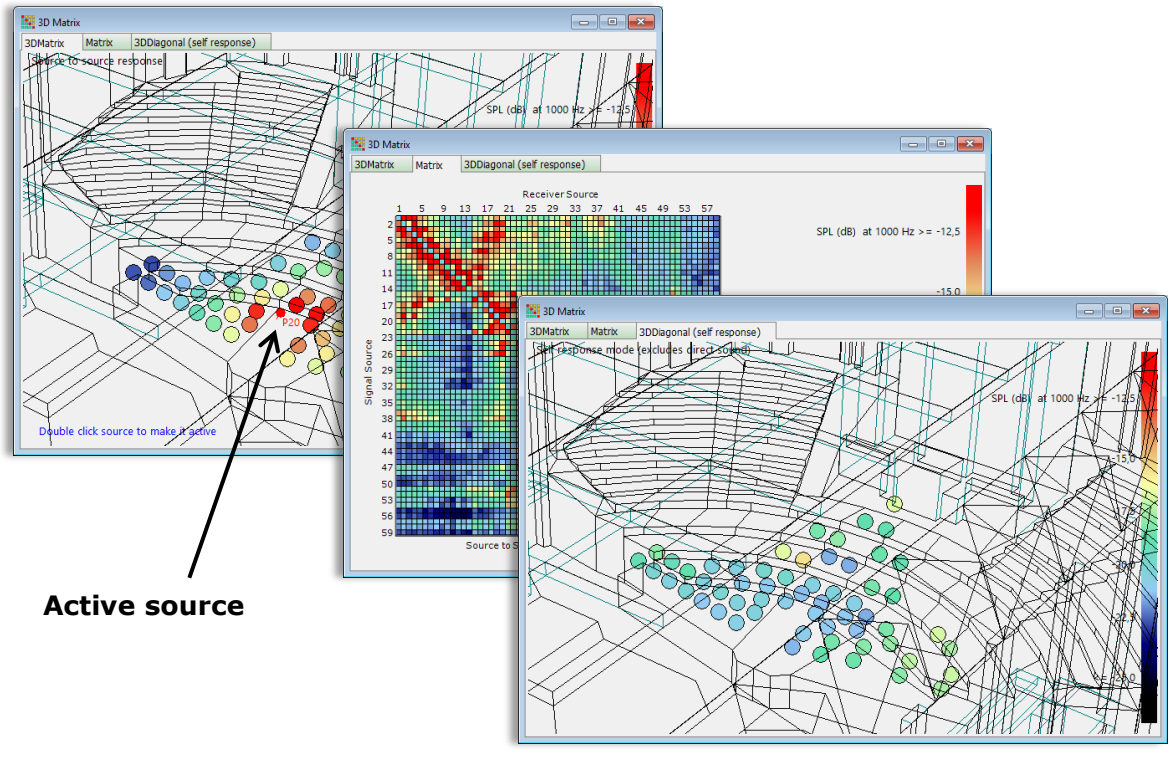
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virtually place yourself in the room and listen to what any signal sounds like at that position. Please read Chapter 7 for a detailed tour.

5.3 3D-matrix Calculation

The 3DMatrix calculation is a special type of point response calculation which allows investigating the response from one source position at other source positions without the need to define any receiver positions. This makes it easy to investigate scenarios where sources by nature acts as receiver as well. Examples on this may be the occupants in an open plan office or the musicians in an orchestra.
The 3DMatrix utility calculates a matrix of all the point responses from each point source to all the other point sources. So, if three-point sources are defined then nine combinations are calculated; S1S1, S1S2, S1S3, S2S1, S2S2, S2S3, S3S1, S3 S1 and S3S3.
The responses S1S1, S2S2 and S3S3 are special in that the source and the receiver positions coincide. Obviously, the direct sound in these combinations would go to infinity due to the source-receiver distance of zero. So, in these cases ODEON excludes direct sound. These values occupy the diagonal in the source-to-source matrix and are referred to as diagonal values. Although the diagonal values are not values that can be physically measured, we do believe that the values can give valuable information e.g. as to how loud the room sounds from the source's point of view.

The 3DMatrix window has 3 tab-sheets:
3DMatrix, Matrix and 3DDiagonal (self-response). For all the displays the selected parameter is displayed at the selected frequency (for parameters that are frequency dependent).
In the 3DMatrix display, double click on a source to make it the active one. Its response is then visualized at the other source positions. The Matrix display is difficult to read as there is no obvious way to order the sources at the two axes (source/receiver) e.g. by distance. However, as all values are displayed at one graph, it is possible to spot extreme values. Double clicking a value in the graph and that value will be displayed in the appropriate 3D display – the 3DMatrix or the 3DDiagonal. The 3DDiagonal shows all the diagonal values for all sources in one 3D graph.



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5.4 Results from measurements

All ODEON editions include a measuring system that makes it possible to capture impulse responses in real rooms. ODEON calculates all parameters from measured impulse responses and allows comparison with simulations within the Multi-point response as well as the Compare and average multi-point responses interface. For a full overview of results from measurements see in Chapter 12.

5.5 Visualisation Tools

Visualisations in ODEON help to get the overview of sound propagation in the room model and they form a great tool for demonstrations to clients that are not familiar with Room Acoustic Parameters and scientific terms. Visualisations can provide great screenshots and animations for presentations, but should not be used for accurate predictions.

 3D Billiard

A number of billiard balls are emitted from a source position and gets reflected by the surfaces of the room. This is a useful animation tool which visualizes how a burst of sound will propagate in the model and allows tracking specific phenomena like flutter echoes between parallel walls or focusing from curved geometries. Scattering is included in the animation and to some degree it is also possible to enable visualization on how sound gets absorbed. By default, balls change colour every time they are reflected from a surface, as an alternative, colour can be used for visualization of sound strength. Read more about the different options by pressing F1 in the in this window or by seeing our tutorial videos on our website.

 3D Reflector Coverage

In the 3D Reflector coverage, you can visualize which areas a given reflector will cover, up to the specified order of reflection. Use the Define reflector surfaces window  first in order to define which surfaces in the model will act as reflectors.

 3D Investigate Rays

Rays are emitted from a source, and you can view them as they reflect from the surfaces in the room. This is mainly a tool that can be used for checking the geometry for holes. Enable the Display sticky lost rays only option to be able to see where rays escape from the geometry in order to locate leaks in your model. It can also be used for purposes like investigating how the scattering coefficients affect backscattering in tunnels, or in what way sound is distributed in coupled volumes.

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6 Colour Grids – colour maps

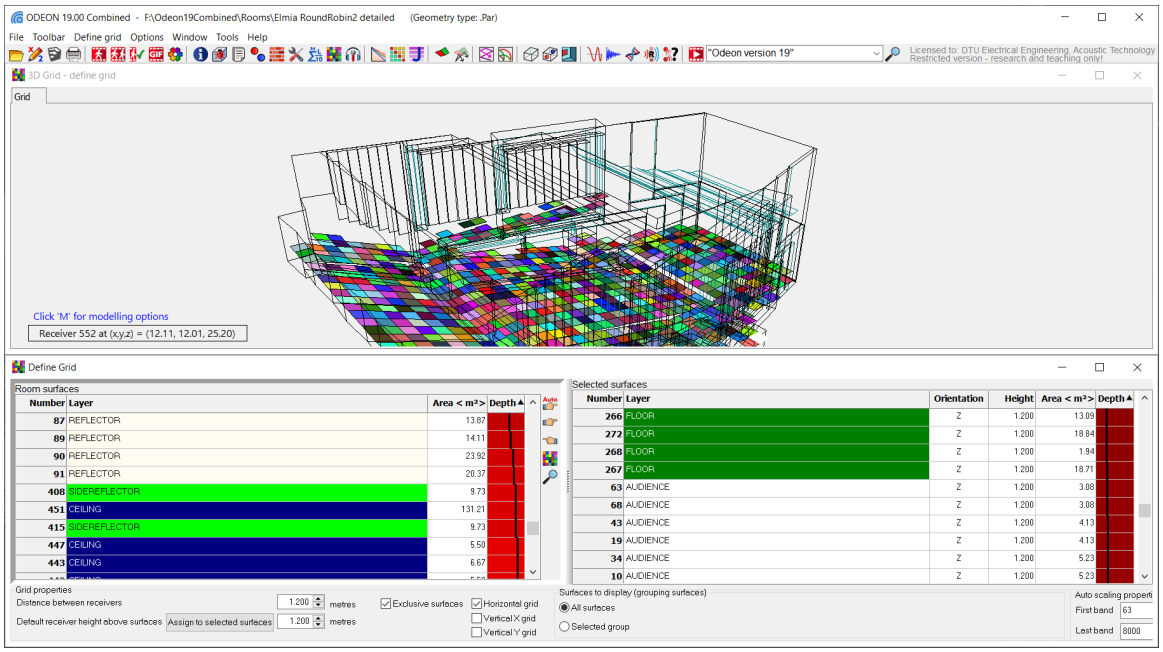
(All editions, except Basics)

6.1 Overview

The 3DGrid display displays maps room acoustics parameters in the 3d model. It is a good way to present an acoustic parameter in the complete room or for a selected part of it using grid groups. It can be used for displaying the variation throughout the room, to provide statistics for the selected grid receivers (grid group) and it is a useful for spotting locations of acoustical problems as well. The colour grids option is first presented in the *Quick Start Guide* and the help file contains a lot of information (press F1 from within the 3DGrid display). This chapter will give an overview and some extra details. Grids can be defined, calculated and manipulated in four places inside ODEON: In the Define Grid, in the Job list, in the View grid response and in the Room Acoustic Parameter list.

Define grid

These windows are where you define which surfaces you want to make grids on. The left side contains a list of the Room surfaces. Choose to show horizontal and/or vertical surfaces from the options at the bottom. Use the Depth column to help you locate the surfaces you are interested in. Sort surfaces by clicking on the arrow just next to the column title. Use the hand ☞ to move surfaces to the right side that contains the list of Selected surfaces for the grids.



You have multiple setup possibilities. Some of them are:

- Choosing the distance from the surface to the hovering grid.
- Choosing the same surface multiple times with different distance to make grids in layers.
- Choosing the distance between receivers (squares) in the grid, thus changing the resolution. Be aware that higher resolution increases calculation time exponentially.
- Grouping the grid surfaces – which will allow display of selected parts of the grid (and calculation of statistics of that subset of the grid receivers).

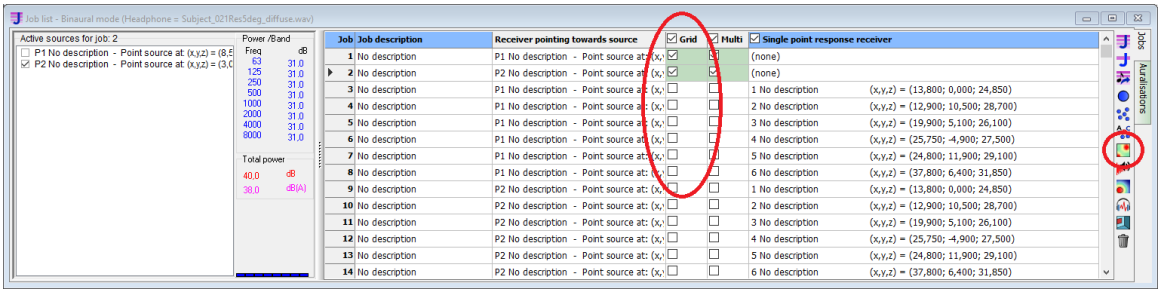
Use the context sensitive help (F1 shortcut) to learn more about the individual options.

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Remember: Before any calculations have actually been performed, the colours displayed in the Define grid are random.

Joblist

The Joblist is the window where you choose for which jobs to make a grid calculation and thereby which sources should be active. Enable the grid calculation for a Job by checking the Grid checkbox for the job(s) you are interested in. To calculate jobs, click the Run Single Job or Run All Jobs button in the right-side toolbar of the Job List. Once a grid job has been calculated its cell in the Job list will be green, to view results click the View grid response in the right-side toolbar of the Job List.



The sound sources for the grid calculations will be those activated for the job. The receivers however, does not relate to the job, instead each grid receiver is the centre of each of the squares as defined in the Define Grid windows.

View grid response

Once a job containing a grid has been calculated (turns *green*), it is ready to display grid results. Click View grid response to see the calculated grids. Use the arrow-keys to change parameters (Left/Right) and frequency band (Up/Down).

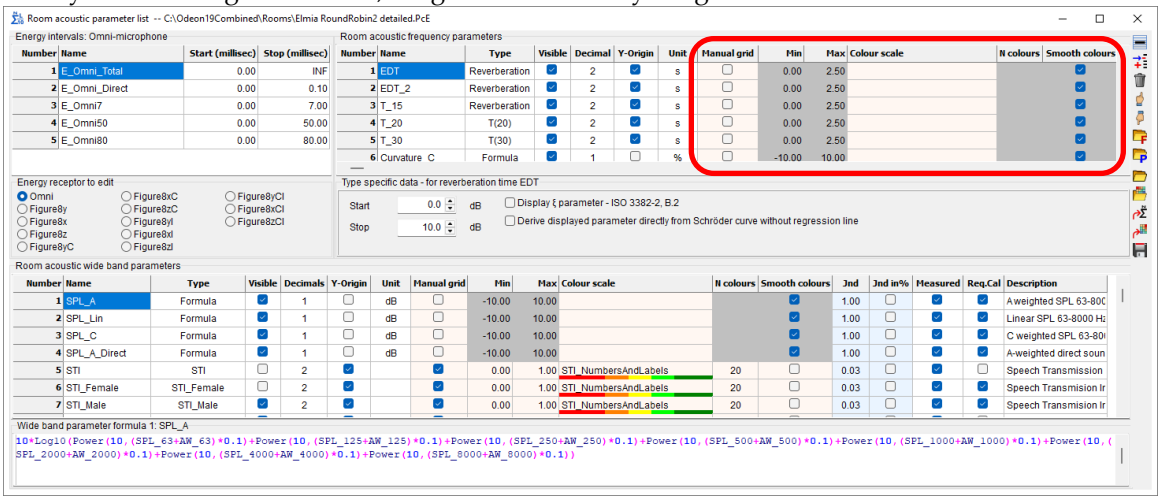
By default, an *interpolated grid* is displayed. Click 3D Grid|Interpolate Grid (shortcut I) to disable interpolation and see the individual calculated grid receivers (squares).

If grid groups have been defined in the Define Grid window, then it is possible to display subsets of the grid surfaces using the G and Shift+G shortcuts.

Remember: Disabling the Interpolate Grid option (shortcut I) will allow you to navigate between grid results faster.

Room acoustic parameter list

Here you can change the colour, range and labels for your grids.



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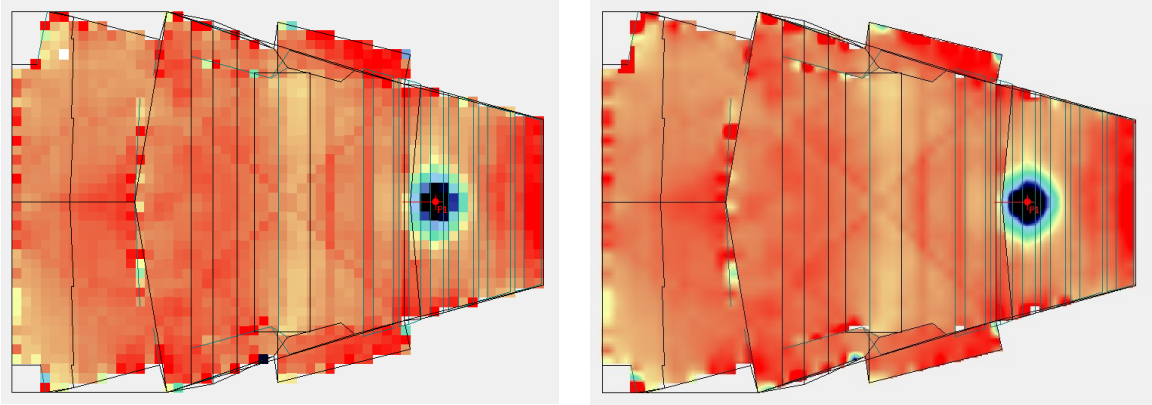
6.2 Accuracy in the Interpolated Grids

As a default Odeon displays grids using interpolation between the limited number of discreate receiver points in the grid. This makes it possible to obtain visually appealing maps for reports much faster, since one can achieve a very smooth grid map with few grid receivers (squares). You can toggle between the interpolated grids and discrete receivers (squares) by choosing 3D_grid|Interpolate Grid (I shortcut) while working in the View grid response.

Even though grid interpolation looks better when only a limited number of grid receivers are calculated, be aware that the actual calculation is still done for the limited number of grid receivers defined. Keep in mind that the grid resolution should be high enough (and the receiver distance small enough) to display interesting trends in the room. On the other hand, a coarser grid will speed up the calculations and might look smoother whereas a too fine grid might give a false idea of how accurate the model actually is. Find your own compromise between the two, considering the room size, complexity of the geometry and calculation time.

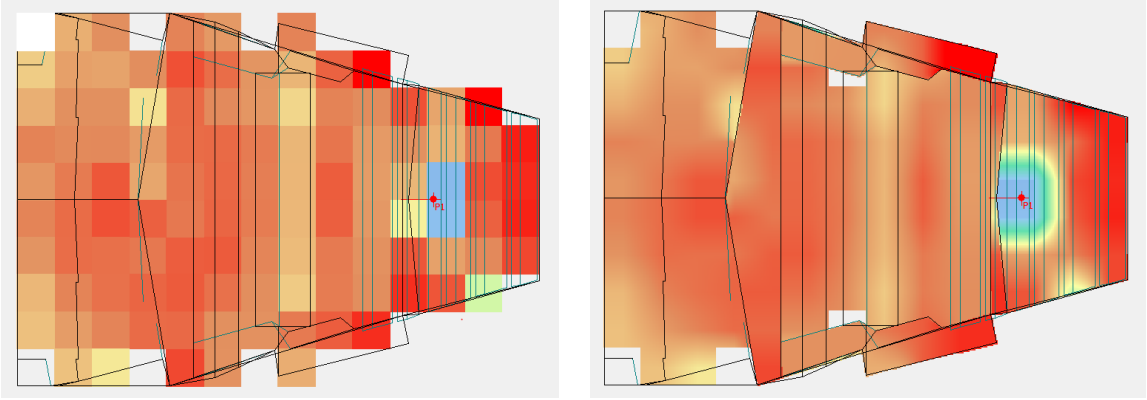
Quite fine grid with 0.75m between receivers:

EDT:



Quite rough grid with 3m between receiver:

EDT:



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6.3 Range, Colours and Labels for Grid Display

There are three display parameters for the grids of each acoustic parameter: range, colours and labels.

Range

The range of the grid (min to max values) is set automatically by default for most acoustic parameters. For STI and similar parameters the limits are by default set to a manual scale ranging from 0 to 1. For the other parameters, the range will start around the lowest calculated value (extreme values are excluded) and go to around the highest calculated value (extreme are excluded). The min and max values for each parameter are the same across the octave bands.
To use a manual grid range, go to the Room acoustic parameter list and press the Expand tables button in the upper-right corner. Check the Manual grid box for the desired parameter and set the new min and max values. The manual ranges remain fixed between calculations, making it easier to compare results before and after a change in the model. Using a manual fixed range may also be useful if comparing grids from different rooms.

Colour and Labels

By default, only a few colour scales are used: the Geography-inspired colour scale and the STI-color scale. Particularly for the STI parameters, the colour scale is divided into different categories from "Bad" to "Excellent".
Colour scales can be defined for all parameters in the Room acoustic parameter list. A few of these include labels. You can also make you own colour scale with labels from scratch, but this is a bit more complicated. It requires to copy and edit one of the .clr files found in the C:\ProgramData\Odeon folder. The ProgramData folder is hidden in Windows by default but you can access this ODEON folder form the menu Options|Explore Odeon Application data folder from within ODEON.

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7 Auralisation

(Auditorium and Combined editions only)

Auralisation in ODEON makes it possible to listen to the acoustics of a room, either from simulations or measurements. It provides a more subjective experience to the listener, compared to only providing acoustic parameters. It can also be a good way to present acoustical results for a client who is not familiar with acoustic terms and parameters.

Auralisation consists of pairing the acoustics of a room with audio files. Typical examples include auralising a crowd in a canteen, an orchestra in a concert hall, disturbance from co-workers in an open plan office, etc. You can listen to the results either via headphones or loudspeakers.

Although ODEON tries to make auralisation features as user-friendly as possible, it involves many different aspects, such as room acoustics modelling, signal processing, wave signal files, transducers, psychoacoustics and recording techniques. This chapter can help you make the most out of the auralisation tools in ODEON. You can also find more resources on our website, including an article on auralisation and many video tutorials.

The field of auralisation makes use of many specific terms. Please refer to **Appendix A: Vocabulary** for a short description of frequently used words. In this chapter, it is assumed that you are familiar with the basic auralisation functions in the *Quick start guide* for ODEON Auditorium or ODEON Combined. The *Quick start guides* can be found on ODEON's website.

7.1 What is Auralisation

When you make an auralisation, you pair an input audio file (typically anechoic) with the acoustics of the room (Vorländer, 2008).

Auralisations are most often based on *anechoic recordings*, which do not contain any reflections or any room acoustics effects. The anechoic audio file can be anything like speech, music, common sounds or noise. The mathematical process behind auralisation is called *convolution*. The acoustics of the room are represented by the room's *impulse response*, which is the function that is convolved with the anechoic input signal. The room's impulse response is determined at a specific receiver position for a given source position. The direction of the receiver is also crucial as it represents the orientation of the listener's ears relative to the source. The resulting audio signal corresponds to how the input signal would sound in the room, at the position of the impulse response. Room acoustic effects such as reflections, echoes or reverberation will be perceivable.

ODEON provides different playback options, either through headphones or a custom surround sound system.

Input audio signals

In most cases, the input signal should be anechoic. Such audio files are typically recorded in an anechoic environment, so that they do not include any room reflection. Occasionally, it can be acceptable to use a file recorded in a fairly dry room, with a directional microphone close to the source.

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In environments where recorded audio is played through speakers, such as bars, music venues or cinemas, you should use non-anechoic recorded music instead.

The Room Impulse Response

The room impulse response is a signal that describes the room's acoustic behaviour for a specific receiver position and orientation in the room. Room acoustic effects such as reflections or reverberation are included in the impulse response signal. There can be one or multiple sound sources generating the impulse response. A typical multi-source example is a loudspeaker system on a train platform, where each unit emits the same signal.

The room impulse response can either be measured in an actual room or simulated by ODEON. Simulated impulse responses are chosen from the Job List, but in some applications, new jobs and impulse responses are generated automatically. In any case, only one receiver (position and orientation) can be associated to a given auralisation. Note that for many room acoustic parameters, the receiver orientation does not matter, but it is crucial for auralisation.

Reproduction setup

After the convolution, the auralisation results must be played back on an audio system. ODEON provides different options.

Reproduction over headphones

The most common method is to reproduce sound through headphones, as a 2-channel signal. Each channel should then correspond to the signal that would reach each ear in the actual room. This is called *binaural auralisation*.

An important aspect of binaural auralisation is accounting for the listener's body being present in the room. Indeed, the human brain makes use of signal differences between the left ear and the right ear in order to localise sound sources. These signal differences are mainly due to scattering by the head and the torso. When creating auralisations via headphones, adding this effect results in much more realistic outputs, in which sound sources are accurately localised.

For reproduction over headphones, the influence of the listener is typically added to the room's impulse response: we then obtain a *Binaural Room Impulse Response* (BRIR), which consists of two channels, one for the left and one for the right ear, respectively. In actual measurements, the impulse response can be measured at the two ears of a dummy head, which adds head and torso scattering to the measured signals. In ODEON simulations, the listener's influence is added through a bank of *Head-Related Transfer Functions* (HRTF), which contains the response at both ears for waves coming from any direction in free-field. ODEON provides several sets of HRTFs, but they can also be customized to the listener in order to improve the auralisation quality. When the anechoic input signal is convolved with the BRIR and played back over headphones, you should have the impression of listening inside the room without headphones.

Reproduction over a loudspeaker system

Another way of playing auralisation results is using a surround setup, consisting of several loudspeakers, typically arranged around the listener. This option requires a more complex setup, generally in a fairly damped room, with a loudspeaker system installed all around it.

With a loudspeaker reproduction setup, the listener is physically present in the reproduction space, and the listener's body will interact with the sound waves originating from the loudspeakers, so the binaural cues do not need to be added to the reproduction signal.

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Ambisonic output

Another well-known option for auralisation output is the Ambisonics format (also known as B-Format), in which the output signal consists of multiple channels. This format is a decomposition of the signal on a basis of spherical functions, called Spherical Harmonics. The nth channel is the projection of the signal on the nth Spherical Harmonic. Therefore, ambisonics signals inherently include spatial directional information. You can learn more about the Ambisonics format in the following video.

ODEON can provide output auralisation files in B-format, but generally the decoding to a reproduction setup has to be carried out by another software. There are, however, two exceptions:

- The surround sound reproduction is based on the decoding of B-format signals on a horizontal plane.
- The 360Auralisation tool makes use of B-format files to produce a headphone reproduction that includes head rotation in real time.

7.2 Auralisation Overview in ODEON

Auralisation features in ODEON

ODEON contains different tools to produce auralisations.

Convolution tools in ODEON

- **Streaming Convolution:** this is the fastest way of making an auralisation. For every job where a single point response is calculated, you can open the Streaming Convolution tool to listen to different audio files paired with the acoustics of that single point response. This type of auralisation cannot be exported.
- **Offline auralisation:** this is the main auralisation feature of ODEON. The tool allows you to create "large" auralisations, in which multiple sound sources with different signals contribute to the acoustic scene. The calculation is generally too long to be played in real time, but it will be saved into a .wav file which can be played by any audio player.
- **Auralisation from measurements:** anechoic files can be convolved with measured impulse responses in the Play it facility of ODEON. Depending on the type of impulse response, more advance features can be used (e.g. head rotation for B-format measurements). If the impulse response was measured with the Odeon Omni source, you can also compensate for the source's spectrum, which will greatly improve the quality of the rendered signals. You can find more details in the Measurement Chapter, Section 12.8.

Tip: multi-channel simulations are possible in ODEON, but they require multiple jobs in the Job List with the same single point receiver and the same orientation. Examples include simulating a stereo setup, Public Address systems with background noise, or a singer versus an orchestra.

Reproduction setup options

The offline auralisation tool offers three different reproduction modes, which you can toggle between (Shortcut Alt+B).

- **Binaural mode** for listening via headphones. This is a recommended setup, as it is the easiest to reproduce. ODEON will calculate a binaural impulse response for the job in question, i.e. a 2-channel impulse response that corresponds to the signal at the entrance of the left and right ear canals, respectively. Using a proper set of HRTFs and an adequate headphone filter can help enhance the auralisation quality. As the output file is a standard stereo wave file it is easy to transfer and to play on e.g. another PC.

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- **Surround mode**: the auralisation is listened to via a system of loudspeakers placed in a horizontal plane in a damped room.
- **B-format mode:** ODEON can produce output file in the ambisonics B-format. The B-format files can be used directly 360Auralisation (see below) and then the B-format files can be decoded outside of ODEON – e.g. for research using Matlab-code.

Presenting auralisation results

Offline auralisation outputs are saved as wave files (*.wav). There are different ways of exporting and/or presenting these results:

- **Playing wave files in ODEON:** the integrated audio player makes it possible to listen to the output files within ODEON.
- **Exporting wave files:** the generated wave files can be found in the room's folder. You can also drag and drop auralisation results directly from the Joblist|auralisation in ODEON to a specified destination (e.g., a folder in the Windows Explorer or a Power Point presentation).
- **360Auralisation tool (B-format mode):** this tool converts B-format files into a binaural signal, to be played via headphones, in which you can change the listener's orientation in real time.
- **Exporting to Soundscape App:** this option creates a set of auralisation files for different scenarios (materials, receiver positions, different rooms…). The files can be presented via a standalone web application (Soundscape App), where you can easily select and compare the different scenarios.
- **Movie auralisation:** create a .mp4 video file in which the receiver travels on a user-defined path while listening to the auralisation.

Examples of auralisation scenarios in ODEON

ODEON can be used to create a wide variety of auralisation scenes in a given room. Below are some typical examples.

- Quickly evaluate the acoustics of a room during the design phase using the Streaming Convolution tool.
- Play an impulse response for a specific job.
- Simulation of a loudspeaker system (e.g., a PA system in a station), where each loudspeaker plays the same file, using offline auralisation.
- Simulation of a full orchestra, using separate anechoic files for each instrument. You can follow the corresponding video tutorial for more details.
- Simulation of a crowded space, e.g., a cafeteria, using only a few speech signals. A video tutorial is also available for this scenario.
- Move your head while listening to a sound scene at a given position, with the 360Auralisation tool.
- Present different auralisation scenarios to a customer, using the Soundscape web application.

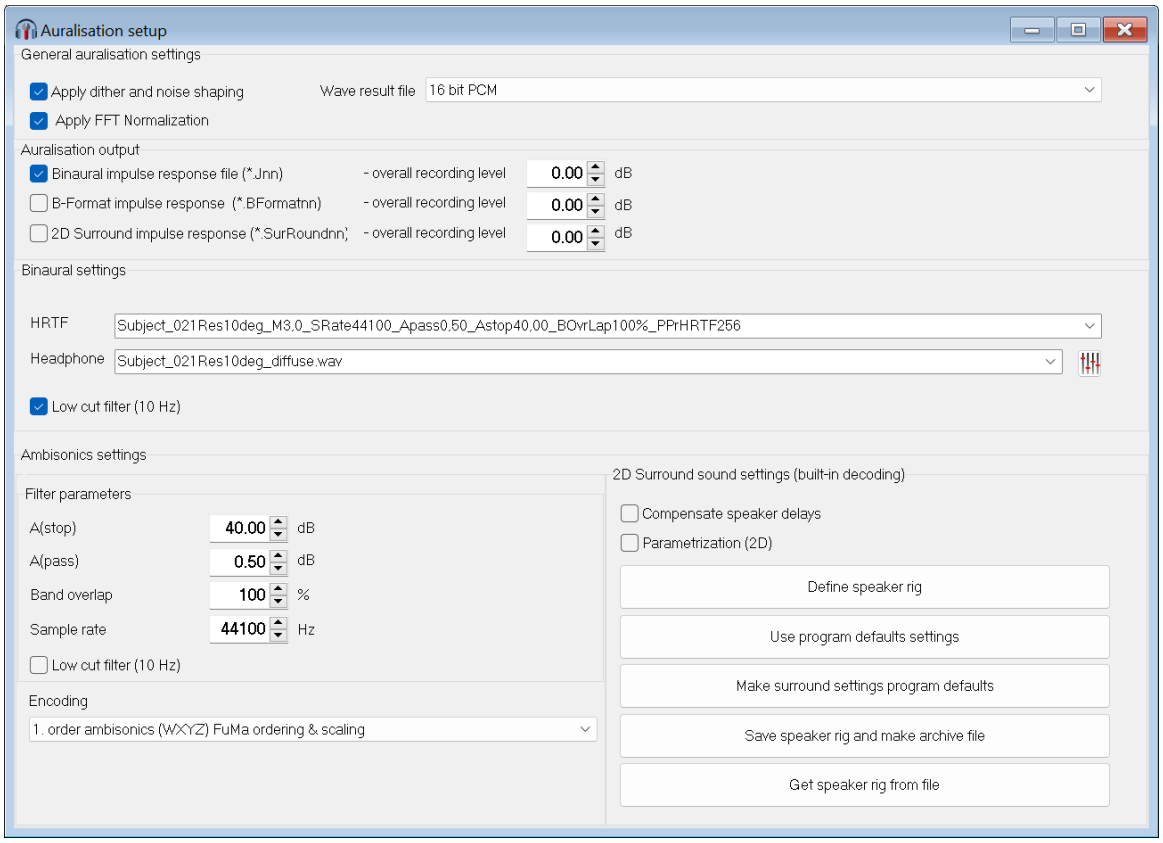
7.3 Setup for Auralisations

The first step to produce auralisations is to define your settings in the Auralisation setup . These settings will affect both Streaming and Offline convolutions. It is in the Auralisation setup that you can choose to generate Binaural, B-format or Surround auralisations, by clicking on the corresponding check boxes. Depending on which mode(s) are selected, ODEON will produce different .wav files, including an impulse response, an output auralisation file (one single source), or an output auralisation mix file (several sources).

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This section covers the main options available in the Auralisation setup, but you can find more information in the help file. Press F1 when you are in the Auralisation setup, and the help menu will appear.

Remember: Always press F1 when you need to learn more about specific functions in ODEON. The context sensitive menu will open at the page related to the active window. Often, the ODEON help file complements the manual and offers extra information. For instance, to learn more about Surround playback and how to define a speaker rig for surround playback – which is not covered here - click the Define speaker rig button in the Auralisation setup then press F1.



In the Auralisation setup, the binaural settings are found in the upper half of the window, the lower-half refers to Ambisonic reproduction.

Binaural settings

These settings concern reproduction strictly through headphones. If you enable the Create binaural impulse response file option, a binaural impulse response will be created with the calculation of any single-point response.

Head Related Transfer functions - HRTF

For most users, the HRTF filters are not very important to learn about in detail. The HRTF file contains the filters that mimics the effect of the head of the listener on the perceived sound. By default, there are two HRTF filters available in ODEON, with different angular resolutions. If you are interested in learning more about the HRTFs or how to add new HRTF files, read **Appendix E**. If you are using HRTFs to calculate the IACC parameter, you will need to create a filtered set of HRTFs for this purpose. Please read Section 8.5 about IACC.

Headphones

The headphones used for auralisations will affect the listening experience, because any pair of headphones will change the frequency response of the auralisation. Therefore, ODEON can

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minimize the influence of the headphones by applying an inverse filter. Either choose one of the given headphone models from the list or add your own. There can be large differences between headphones, so it is important to choose the correct pair when possible. Remember that if you want to present the auralisations to a client, they should be made for the type of headphones the client is using.

For many users, it is not possible to either measure the headphones used or to find a matching one included with ODEON. In that case, you should instead use the diffuse field filter matching the set of HRTFs selected. Odeon automatically creates generic diffuse field filtered headphone filters for each set of HRTF's. For instance, for the HRTFs called `Subject_021Res5deg_...`, the matching headphone filter is `Subject_021Res5deg_diffuse`.

The design of headphone filters is explained in more detail in **Appendix D**, as well as how to add the frequency response of your own headphones in ODEON.

Ambisonics settings

The Ambisonics settings are found in the lower part of the Auralisation Setup window. ODEON can produce either a 3D B-format output, which can be decoded into any loudspeaker system in an external program or a 2D surround output (already decoded in ODEON), which can be played directly on a horizontal loudspeaker system additionally the Ambisonics output is used for the 360Auralisation which allows for real time head rotation during playback. Remember to press the F1 key to find further information from the ODEON help.

Filter settings

This section controls parameters for the filters. For most users, the Ambisonic filters are not very important to learn about in detail, and you should keep the default settings. However, you can read more details and how to change them in **Appendix E**.

Encoding

Specifies the order of the Ambisonic encoding. The higher the order, the more precise the encoding will be. Three orders are available:

1st Order

This provides **4-channel** wave files, **WXYZ**, with W being the omni.

2nd Order

This provides **9-channel** wave files, ordered according to the Ambisonics Component Ordering, ACN (corresponding to Furse-Malham): **WYZXVTRSU** (used to be ordered WXYZRSTUV in Odeon 14 and earlier versions).

3rd Order

This provides **16-channel** wave files, ordered according to the Ambisonics Component Ordering, ACN (corresponding to Furse-Malham): **WYZXVTRSUQOMKLNP**.

Note: Currently it is advised to use **first-order ambisonics** for your ODEON loudspeaker auralisations. Higher orders should in principle give more detailed reproduction, but anyway the implementation of the Furse-Malham algorithm results in a somewhat blurred sound field.

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B-format settings

Use these settings to create a B-format output. Such output is required to use the 360Auralisation tool, or it can also be decoded outside of ODEON to any loudspeaker system.

Check the box Create impulse response (*.BFormat) to create impulse responses in the order defined in the Encoding. These impulse responses will then be convolved with anechoic files in the Job List to provide B-Format convolutions (auralisation files). The B-format convolutions are multi-channel files (4, 9 or 16, depending on the chosen order).

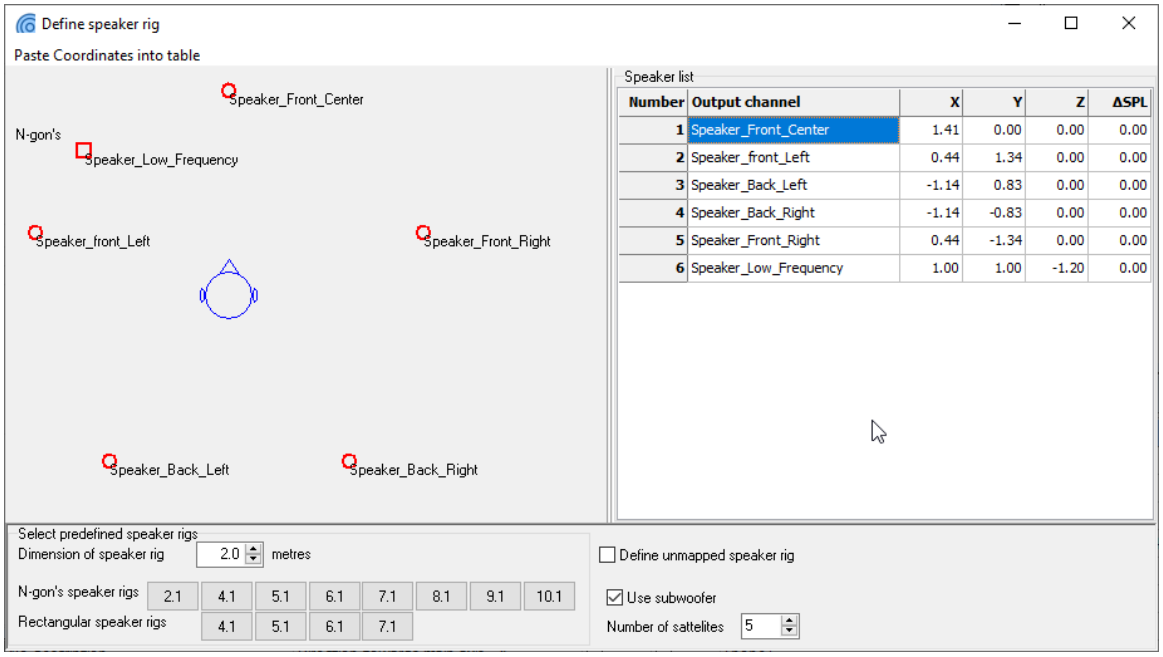
2D surround settings

Use these settings to create a decoded surround output, which can be played directly to a 2D surround system (e.g., home cinema audio systems). The tool does not provide 3D decoding.

Check the box Create impulse response (*.SurRoundnn) to create impulse responses that correspond to each speaker in the defined speaker rig (see below). These impulse responses will then be convolved with anechoic files in the Job List to provide 2D surround convolutions (auralisation files). The Surround convolutions are multi-channel files that include one channel for each loudspeaker and they can be played by any media player.

Several options can help you optimize your loudspeaker setup, including compensating for loudspeaker delays and parametrization to ensure accurate recreation of plane waves. You can find more information on the contextual help by pressing the F1 key. Preset values are available in the program default settings. You can load these with the Use program default settings button, or change the default settings with the Make surround settings program defaults button.

An essential part of the Surround mode is defining your speaker rig, which specifies how the loudspeakers are arranged around the listener. Click on Define speaker rig to access the menu. Some templates are available, the most common being 5.1 and 7.1. The increment .1 indicates the use of a subwoofer, which comes as an additional (omnidirectional) channel in the file (Check/Uncheck the box Use subwoofer). The pre-defined templates are either circular or rectangular, but the coordinates can be adjusted in the right side table to create a fully customised setup.



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Once you have set up your speaker rig, you can save it as a file for future use by clicking on Save speaker rig and make archive file Button. The configuration is saved as a file with the extension *.SurroundSound. The default folder destination is ODEON's application data folder, but you can always choose another location.

Note: you can access ODEON's application data folder and other relevant locations by clicking on Options in the main menu.

Job list settings

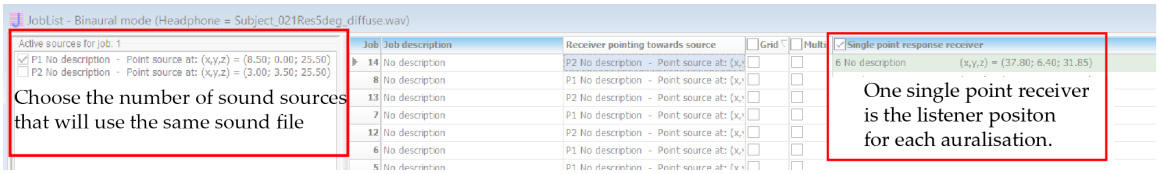
Source and Receiver options

Any auralisation is specific to a single receiver, as a listener will be at one given position at a given time. The orientation of the receiver also affects the auralisation, so it should be properly set in the Job list.

- If you want to make an auralisation with multiple sound sources with different sound files, make a job for each sound source or use the Multi source/signal auralisation expert (see the **Offline Auralisations** section).
- For an auralisation where the same sound file is used from multiple sound sources (e.g. a loudspeaker system), you can simply create one job in which all the relevant sound sources are active.
- For different sound files played from the same source position to the same receiver, you can reuse the same job in different convolutions.

Single Point Response

Auralisations made in ODEON are based on the Single point response receiver jobs in the Job list. Therefore, you have to create jobs with one or more active sound sources and a single receiver.



A note on directivity patterns for natural point sources

It is common to make auralisations with natural point sources. By natural sources, we refer to sources such as human voice, an acoustical instrument or similar, where a recorded signal for auralisation may be associated with a certain directivity pattern. In order to select the right source for auralisation purposes, please read Chapter 3.

Sound cards (audio interface)

A sound card is required in order to play back the auralisation results. As a minimum, the sound card should be capable of handling signals in stereo, in a 16-bit resolution at a sampling frequency of 44100 Hz. Also consider whether the card is immune to electromagnetic noise, which is always present in a PC, and whether the analogue output for headphones is satisfactory.

For surround auralisation, a multi-channel surround sound card is obviously needed, along with the necessary loudspeakers and amplifiers. Sound cards running with an ASIO driver will not work, as the audio output will then appear as a 2-channel signal only. Instead, you should use a sound card with Windows Driver to make sure that all the needed output channels will be accessible.

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7.4 Making auralisations

There are different ways of creating auralisations in ODEON. This section covers the existing options and how to access them. Auralisation from a measured impulse response is not covered in this chapter. You can learn more about this feature in Section 12.8.

Input signals for auralisation – anechoic recordings

For auralisation you will be using input signals to convolve with the calculated impulse responses. Usually, the signals will be anechoic signals, although other types of signals are possible in specific cases (e.g., simulating a stereo setup with a commercial stereo recording). The input signals to be used with ODEON are stored in uncompressed wave files (*.wav). Most resolutions are supported, so files edited by programs such as Audacity or Adobe Audition can be used without any conversion:

- 8, 16, 24, 32-bit PCM.
- 32-bit IEEE Float.
- 8, 16, 24, 32-bit PCM, Extensible (tells the number of significant bits).
- 32-bit IEEE Float, Extensible (includes some additional info which is not used for input by ODEON).

To be compatible with the HRTF's supplied with ODEON the wave files, should have a sampling frequency of 44100 Hz.

Note: 8-bit resolution is not recommended for normal use, but can be useful for educational purposes, in order to demonstrate dithering. Outputs created without the Apply dither and noise shaping option will sound horrific in the 8-bit resolution, and the output quality improves greatly when dithering is enabled. The improvement in quality caused by dithering is less audible at higher bit resolutions – but it is still important.

The ODEON program comes with a some anechoic samples, which can be found in the \ODEON...\WaveSignals\ directory. If you wish to extend the library of input signals, you should put your new signal files here or in a subdirectory, e.g.: \ODEON...\WaveSignals\English voice\ or \ODEON...\WaveSignals\NoiseSignals\.

A growing number of anechoic recordings are available from the Odeon home page. Many of the files come in the form of *.OdeonZipArchives. These files contain all the data needed to run an ODEON simulation, i.e., a complete room model including setup; materials, sources, receivers and jobs, as well as the necessary directivity files and anechoic recordings.

A few audio albums containing anechoic recordings are commercially available, namely the Archimedes album (1992), which contains some recordings of solo instruments and the Denon album (Denon PG-6006, 1988) which contains (semi) anechoic stereo recordings of orchestral music.

Play BRIR – listen to a Dirac signal

Once a Single point response is calculated, it is possible to play the corresponding BRIR, clicking the Play Single Point BRIR button. The BRIR gives a first clue as to how the room sounds and it also allows some evaluation of the quality of the calculated point response, e.g., whether to use a higher number of late rays in the Room setup.

This function requires the Binaural mode to be activated in the Auralisation Setup before calculation.

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Note: a BRIR may sound unrealistic, because it is not a signal that you usually hear in real life. For a more realistic sound, you can convolve it with the signal Clapping, an anechoic recording of hand claps, which is a less transient signal than an ideal impulse.

The BRIR is saved as a .wav file, which can be found in the room's folder. If you want to study the properties of the generated impulse response in more details, you can open this file with the button Load impulse response. The file will then be interpreted as a "pure" impulse response, in terms of pressure (ODEON results are typically energy-based quantities).

Tip: if you want to extract a "pure" impulse response from ODEON simulations, select "unity" as HRTF in the Auralisation setup, and set the Headphone field to blank. The resulting BRIR will have the same signal on both channels, without any head scattering or inverse headphone filtering.

Streaming auralisations – listen to different audio files

For fast evaluation of the acoustics, use the streaming convolution button on the right-hand side of the Job list (on the Jobs tab). The auralisation will be created for the selected job in the Job list. The main advantage is that you can easily switch between different input audio files, and hear how they are affected by the room in real time.

Under Input signal, choose the audio file you want to auralise. If you press Listen to input signal, you hear the anechoic signal, otherwise the convolved signal for the selected job. Under Channel setting you can choose to use a stereo source. This is explained in the help file (press F1 when the Streaming convolution menu is open), but for most cases it is recommended to keep the default Mono source.

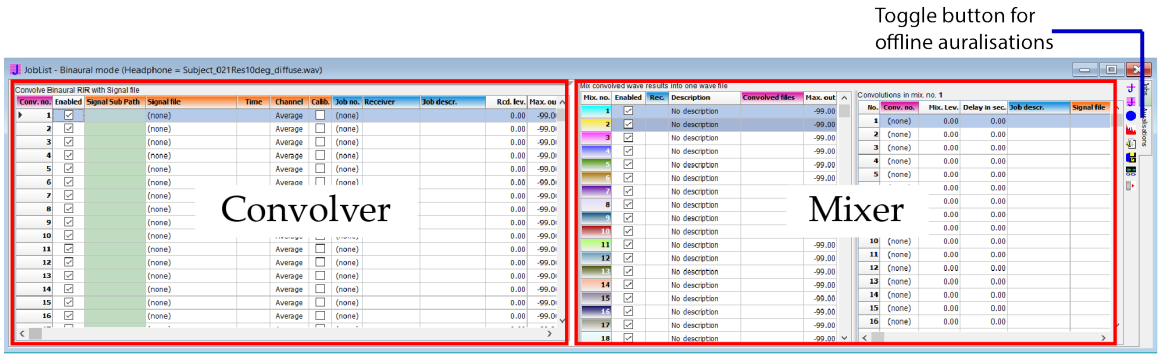
Offline Auralisations

The main auralisation facility in ODEON is offline auralisation which is found on the Auralisations tab of the Job list. It allows you to mix different convolutions together, make individual adjustment on each channel (delay and level), and store auralisation results in .wav files. The audio files can be used externally (e.g. in Power Point presentations), and you can make use of the Soundscape app to present the results on a web page (see Section 7.5).

Auralisations can be set manually, but if many sources and signals are involved, you can use the Auralisation Expert to generate all the needed jobs. Both the manual setup and the Auralisation Expert are explained in this chapter.

Overview of the Auralisations Tabsheet

If at least one of the auralisation options is activated in the Auralisation Setup (Binaural, B-Format or 2D Surround), the Auralisations tab will be visible in the right-hand side of the Job List. The Auralisations tab consists of a *Convolver* table, a *Mixer* table and a range of options on the right-side tool bar.



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In the Convolver (left part), Jobs (Impulse responses) and audio files are paired in different convolutions. In the Mixer (right part), convolutions from the left part can be mixed together.

Warning: The Auralisations tab is disabled if Create binaural impulse response file (.Jnn), Create impulse respone (*.BFormat) and Create impulse response (.SurRoundnn) are disabled in the Auralisation Setup (SHIFT+CTRL+A).

Convolver

The Convolver is the table situated on the left side of the Auralisations menu. This is where the single auralisations are made manually. Here, mono signals are convolved (paired) with the simulated impulse responses (Binaural, B-Format or Surround), which are calculated as part of the Single Point Response. The result is the auralisation of a single audio file from one source, as indicated by the selected job.

Note: the title above the convolver changes according to which auralisation mode you are in. You can toggle between modes using the toggle button, (Alt+B).

The part of the table with an orange header concerns the input signal. You can select the following options:

- Signal Sub Path: subfolders of the Wave signals folder (as set in the Program Setup). When left blank, you are situated at the root of the Wave signals folder.
- Signal file**:** name of the chosen anechoic input file for the auralisation. This list contains the files located in the specified Signal Sub Path. The Time column (duration) is automatically updated when a file is selected.
- Channel: for multi-channel input files, select which channel is used as input. By default, an Average of the channels is used.
- Calib.: when checked, ODEON will 'calibrate' the level of the input to have a fixed A-weighted level. Then, two different recordings, e.g., voice and noise, will have a comparable loudness. The adjustment is done before the files are convolved with the impulse response.

The part of the table with a blue header refers to the selected job for the auralisation. You should select a job number (Job No. column) from the Job list. The Receiver and Job descr. columns will update automatically. Only jobs with a defined single point response can be selected.

The two last columns refer to the convolution level:

- The Rcd. Lev. column is the recording level of the input file. By default, it is set to 0 dB but you can change it if the output convolution ends up too loud or too quiet.
- After the calculation, Max. out displays the peak level of the resulting convolution. The Max. out level must be close to 0 dB for an optimal dynamic range, but never above 0 dB, in order to avoid digital clipping.

Mixer

The mixer is located on the right side of the Auralisations tab. The mixer allows convolved results to be combined into one wave file, allowing multi-channel simulations, such as stereo setups, singer versus orchestra, crowd auralisation, etc. You can add up to 300 convolutions, as long as they have the same receiver position and orientation.

The mixer consists of two lists. The first is the list of all mixes, Mix convolved wave results into one wave file. The second one is the list of convolutions included in the selected mix, Convolutions in mix no. <xx>.

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Remember: Only convolutions that use the *same receiver* and *receiver orientation* can be included in one mix. The listener's head should be at the same position and with the same orientation for multiple sounds to add realistically.

The first list, Mix convolved wave results into one wave file, displays information on the mixes. The only columns that can be directly modified are

- Enabled, which allows turning on or off a mix when you run all jobs.
- Description, which is recommended if you have many different mixes.

The second list Convolutions in mix no. <xx> contains information on the convolutions included in the selected mix. On each line you can specify:

- Conv. No.: the number of the convolution, as indicated in the convolver list. After selecting a number, the corresponding Job descr. and Signal file are automatically updated, according to what is displayed in the convolver list.
- Mix. Lev: indicates the level of the convolution in the mix.
- Delay in sec.: you apply delay to some of the convolutions. This is used if you wish to delay the playback of some of audio tracks in the mix in order to build an audio scene. This should not be confused with the delay that can be applied when defining sources (loudspeakers) with the purpose of optimizing localisation of the primary source (e.g. a speaking person) or in order to deal with echo problems.

Your choice of convolutions will also update the receiver number (Rec.) and the Convolved files column of the first table (pink header) in the first table.

The column Max. out in the first list of the mixer is only updated after the mix has been calculated. It shows the peak level of the output mix file. This level should be below 0 dB in order to avoid digital clipping but it is recommended to keep it close to 0 dB for higher dynamic range.

Warning: there are several different numberings at stake in the Auralisations tab, and they should not be confused.

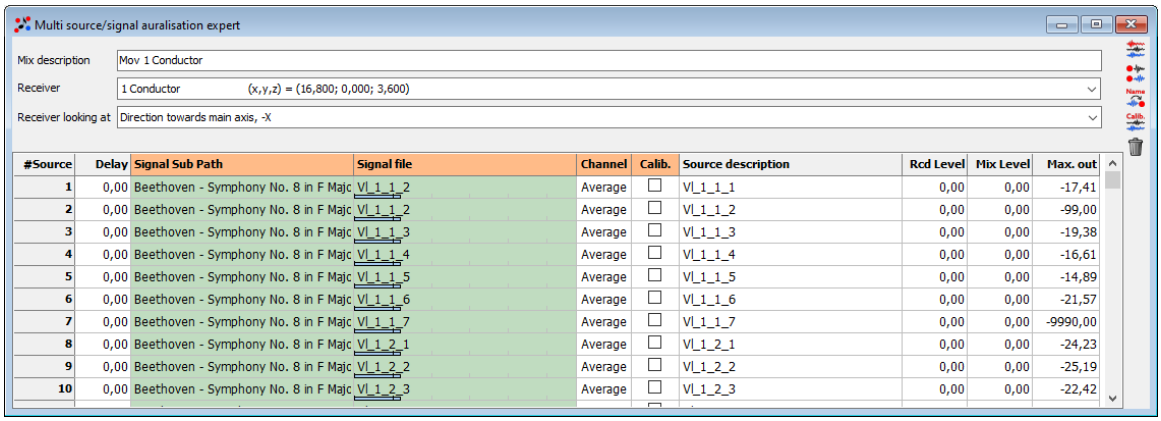
- **Job numbering:** refers to the Job number in the Job list. Only jobs with a single point response enabled are available.
- **Convolution numbering:** refers to single convolutions (1 input file paired with 1 job), as listed in the *convolver* list. Each convolution is assigned a job number, but these two numbers are not necessarily the same.
- **Mix numbering:** identifies an auralisation mix, as indicated in the *Mixer* list. A given mix will typically contain several single convolutions.
- **Convolution in mix numbering:** this numbering is specific to a given mix, and it is shown in the right-most table. Each convolution in Mix number is associated to a convolution number from the *convolver* list, but the two numbers are not necessarily the same.

Multi Source/Signal Auralisation Expert

Setting up complex mixes with many active sources (e.g., a crowd in a canteen or a full orchestra in a concert hall) can be a tedious process. The Auralisation expert makes it much faster. The Auralisation

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Expert button can be found in the right-hand side toolbar of the Job List, but first you need to select the mix you want to edit in the middle table on the Auralisations tab-sheet.



#Source	Delay	Signal Sub Path	Signal file	Channel	Calib.	Source description	Rcd Level	Mix Level	Max. out
1	0,00	Beethoven - Symphony No. 8 in F Majc	Vl_1_1_2	Average	☐	Vl_1_1_1	0,00	0,00	-17,41
2	0,00	Beethoven - Symphony No. 8 in F Majc	Vl_1_1_2	Average	☐	Vl_1_1_2	0,00	0,00	-99,00
3	0,00	Beethoven - Symphony No. 8 in F Majc	Vl_1_1_3	Average	☐	Vl_1_1_3	0,00	0,00	-19,38
4	0,00	Beethoven - Symphony No. 8 in F Majc	Vl_1_1_4	Average	☐	Vl_1_1_4	0,00	0,00	-16,61
5	0,00	Beethoven - Symphony No. 8 in F Majc	Vl_1_1_5	Average	☐	Vl_1_1_5	0,00	0,00	-14,89
6	0,00	Beethoven - Symphony No. 8 in F Majc	Vl_1_1_6	Average	☐	Vl_1_1_6	0,00	0,00	-21,57
7	0,00	Beethoven - Symphony No. 8 in F Majc	Vl_1_1_7	Average	☐	Vl_1_1_7	0,00	0,00	-9990,00
8	0,00	Beethoven - Symphony No. 8 in F Majc	Vl_1_2_1	Average	☐	Vl_1_2_1	0,00	0,00	-24,23
9	0,00	Beethoven - Symphony No. 8 in F Majc	Vl_1_2_2	Average	☐	Vl_1_2_2	0,00	0,00	-25,19
10	0,00	Beethoven - Symphony No. 8 in F Majc	Vl_1_2_3	Average	☐	Vl_1_2_3	0,00	0,00	-22,42

The Auralisation Expert is a really easy way to convolve and mix multiple audio files with multiple sources, for a specific receiver position. This tool works very well with the Audio Effects tool that can create multiple different audio files from a single audio file. The Audio Effects tool is explained later in the chapter (Section 7.5).

The options in the Auralisation Expert are:

- Mix description (optional): It can help identifying the mix, e.g., “Crowd for canteen” or “Orchestra at conductor’s position”.
- Receiver: It is the listener position in the room. All convolutions included in the mix will be simulated at this position.
- Receiver looking at: It defines the direction of the receiver. You can choose the x-axis direction, or point it towards a source position. If you want the receiver to look at a specific direction, in which there is no source, you can create a dummy source in the Source Receiver List.
- List of sources: The list displays all sources available in the Source Receiver List, and shows which signal is assigned to each of them. Not all sources need to be assigned a file, as not all of them need to be included in the mix.
- Select multiple signal files : is a button in the upper-right corner of the Auralisation Expert. Use it to assign multiple signal files to multiple sources. First select the desired sources in the list using Ctrl + mouse click then click the Select multiple signal files icon and select the desired audio files in the file dialog. When closing the file dialog, the files will be added to the selected sources in the list. If you fail to select a matching number of sources and signals, ODEON will try to match them anyway – and usually this works out OK.

When you close the Auralisation Expert, Single point responses, convolutions and the mix are automatically set up. However, they still remain to be calculated.

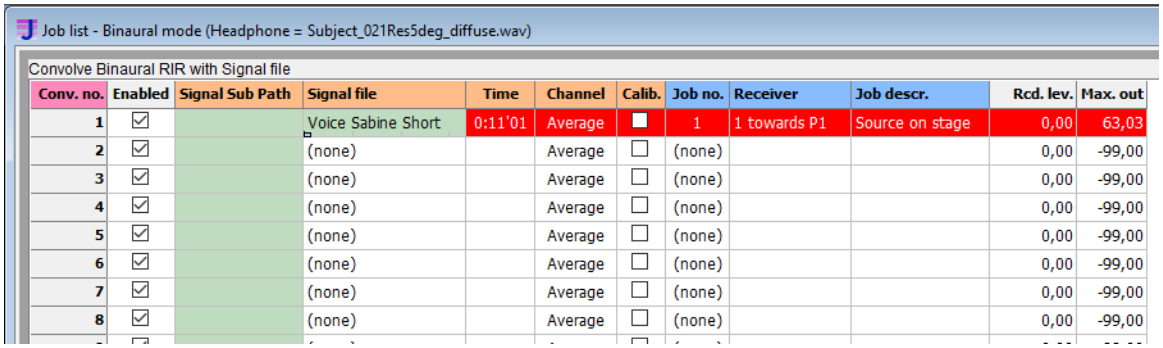
Run the calculations

When a mix has been set up in the Auralisations tab-sheet, you can calculate it by selecting it in the Mixer and pressing Run Single Job, or pressing Run All Jobs. The appropriate rows in the mixer will turn green when the results have been calculated.

When Max. out exceeds 0 dB (for a convolution or a mix), the resulting auralisation signal will be subject to digital clipping. The corresponding line will be displayed in red. In that case, you should reduce the recording level, either in the Convolver for individual auralisations (Rcd. Lev.), or in the Auralisation Setup menu for mixes (Overall recording level). We recommend reducing the level by about the same amount as indicated in Max. out. For example, if the Max. out level is 62.3 dB, you should

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set the recording level to -63 dB, so that the Max. output level will be just below 0 dB after recalculation. Note that the playback volume can still be adjusted by the Windows volume control.


Job list - Binaural mode (Headphone = Subject_021Res5deg_diffuse.wav)

Convolve Binaural RIR with Signal file

Conv. no.	Enabled	Signal Sub Path	Signal file	Time	Channel	Calib.	Job no.	Receiver	Job descr.	Rcd. lev.	Max. out
1	☑		Voice Sabine Short	0:11'01	Average	☐	1	1 towards P1	Source on stage	0,00	63,03
2	☑		(none)		Average	☐	(none)			0,00	-99,00
3	☑		(none)		Average	☐	(none)			0,00	-99,00
4	☑		(none)		Average	☐	(none)			0,00	-99,00
5	☑		(none)		Average	☐	(none)			0,00	-99,00
6	☑		(none)		Average	☐	(none)			0,00	-99,00
7	☑		(none)		Average	☐	(none)			0,00	-99,00
8	☑		(none)		Average	☐	(none)			0,00	-99,00

7.5 Playing auralisations

Apart from Streaming auralisation, which produces audio in real time, auralisation results in ODEON are stored as audio wave files (*.wav).

Wave file results in Auralisation

Auralisations in ODEON create different .wav files, namely impulse responses, single auralisation files (convolution of one signal, as defined in the convolver list), and auralisation mix files (combination of several signals, as defined in the Mixer list). These files can be found in the room's folder, and their name depends on which auralisation mode you use. Below is a summary of the available extensions.

	Impulse response	**Single auralisation**	**Auralisation mix**
Binaural mode	.J*NN*.wav	.ConvAural*MM*.wav	.MixAural*LL*
B-format mode	.BFormat*NN*.wav	.ConvBFormatAural*MM*.wav	.MixBFormatAural*LL*.wav
Surround mode	.SurRound*NN*.wav	.ConvSurRoundAural*MM*.wav	.MixSurRoundAural*LL*.wav

NN: Job number, *MM*: Auralisation number, *LL*: Mix number.

The number of channels in the output files depend on the auralisation mode:

- Binaural files contain 2 channels – left ear and right ear.
- For ambisonics files, the number of channels depends on the chosen ambisonics order:
  - 1st order: 4 channels
  - 2nd order: 9 channels
  - 3rd order: 16 channels
- For surround sound files, the number of channels corresponds to the number of loudspeakers in the surround system.

Playback in ODEON

In order to listen to an auralisation directly in ODEON, click the Play wave result button. An audio player will then appear. The Play wave result is sensitive to the last selection in the Auralisations tab.

- If you select a row in the Convolver list and click on one of the columns with an orange header (Signal Sub Path, Signal File, Time, Channel, Calib.), the (anechoic) input file is played.
- If you select a row in the Convolver list and click on one of the columns with a blue header (Job no., Receiver, Job descr.), the corresponding convolution is played.
- If you select a row in the Mix convolved results into one wave file, the corresponding mix will be played.
- If you select a row of the Convolutions in Mix no. XX, the single convolution file is played.

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Remember: you have to select one of the cells that refer to the Job (e.g., Job no., Receiver, Job descr.) in order to listen to the convolution result.

It is important to consider at which level the auralisation should be played in order to sound realistic. Some guidelines are given in **Appendix F** for binaural auralisations, and an application note is available online for reproduction over loudspeakers.

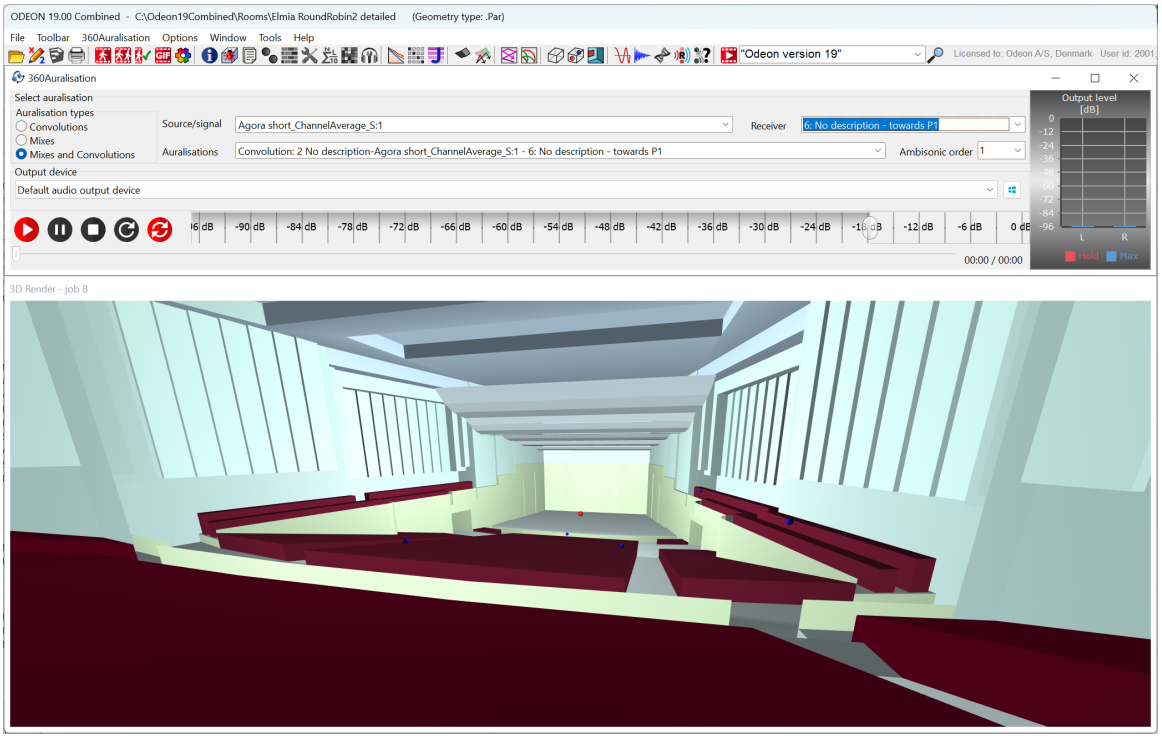
Exporting wave files

If you want to export the wav file, there are several ways to do it.

- You can save it from ODEON's wave player when it is open.
- Another way is to simply drag and drop the wave file from the appropriate cell in the Job list|Auralisations list into the desired destination, e.g. a folder in Windows Explorer, your Desktop or directly into Microsoft Power Point.
- If you need to exchange many wave result files, then you can find all the wave files in Windows Explorer; open the appropriate room folder using the File|Explore current room folder.

360Auralisation tool

The 360Auralisation display makes it possible to listen to an auralisation output (mix or single auralisation) using headphones while rotating the listener's head. The receiver is still at a fixed position, but the orientation can be changed in real time. A 3D rendering of the room helps you monitor the orientation.



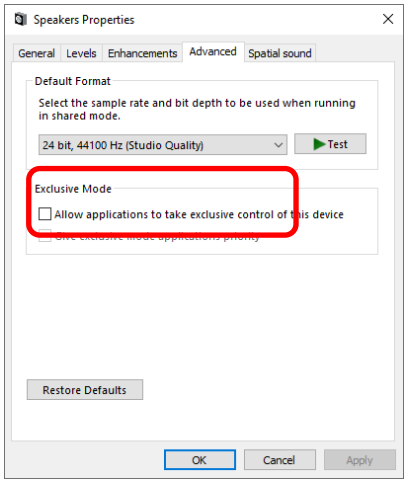
The tool requires auralisation files in B-format, so you should make sure that the B-format option is selected in the Auralisation Setup. The B-format file is then converted into a binaural signal accounting for the head's orientation in real time (Zaunschirm, et al., 2018).

The 360Auralisation tool is accessed via the icon in the Auralisation list. If a specific line is selected, then the first auralisation presented in the tool will be that one (whether it is a single convolution or a mix). In any case, you can browse through your auralisations directly in the tool.

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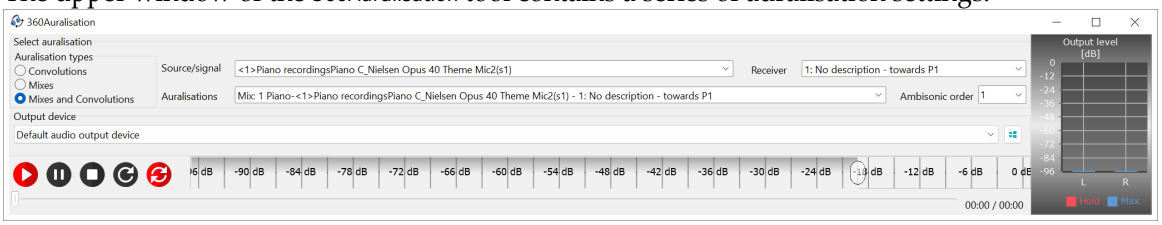
Requirements

- The auralisation files should have been calculated and be available in B-format.
- If the B-format files were calculated with an order higher than 1, then its possible to select the ambisonics order 360Auralisation display.
- The result should be listened to via headphones, as it is a binaural output.
- If you use your own HRTF bank, make sure it has at least 3 elevation planes (including the two poles). All HRIRs should have either 128 or 256 samples per direction.
- The sampling frequency of the HRTFs should match the one of the auralisation files.
- Make sure you also have a matching sampling frequency in the speaker properties from the computer settings.



Functionalities

The upper window of the 360Auralisation tool contains a series of auralisation settings.



In Auralisation types, you can choose to browse through either single convolution, mixes or the both of them. There are three different ways of browsing through the calculated auralisations:

- **Source/Signal:** different input signals and/or source positions. Note that this menu displays all available source-signal combinations. For instance, if the same signal is used for different sources, it will appear as many times as the number of sources it is associated with. If you have defined mixes, this menu will also contain the complete source/signal configuration of each available mix. In that case, the entry first contains the number of active sources in the mix, and then shows which signal is assigned to each source.
- **Receivers:** different receiver positions and/or orientations.
- **Auralisations:** full list of auralisations as defined in the Auralisation tab of the Job list. The list contains single convolutions, mixes or both, depending on your selection in Auralisation types.

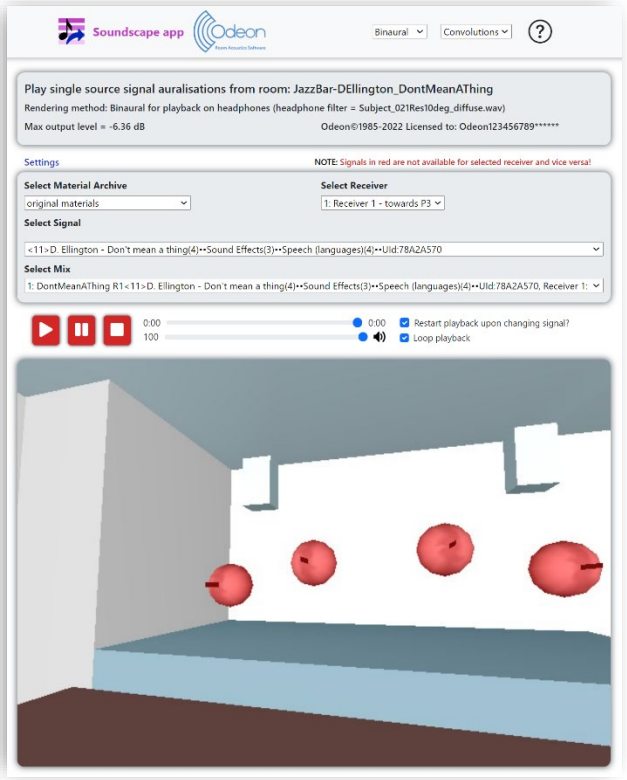
In the dropdowns for Source/Signal and Receiver, the red entries indicate Signal-Receiver combinations that have not been calculated in ODEON. If you select one of these red entries, ODEON will switch to an existing Signal-Receiver combination that contains your selection. Therefore, the selected Auralisation entry will change automatically.

You can change the audio output in the Output device field. Note that the selected output should contain 2 channels, as the auralisation should be listened to via a pair of headphones.
The lower window is the 3D Render of the room at the receiver's position. You can freely rotate the view and the auralisation output will be updated in real time. However, it is not possible to navigate from this position. If you want to listen at another location, make sure to create another auralisation at that position beforehand, and use the Receiver dropdown menu in the upper window. The auralisation and the 3D Render view will update to the new receiver position.

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Soundscape app

ODEON's Soundscape app is a standalone web application which makes it possible to present auralisations outside of the ODEON software, for instance to clients or non-users of ODEON. The Soundscape app is a great tool to compare different scenarios, such as different material configurations or positions in the room. You can export either single convolutions or auralisation mixes. Try the Soundscape app online here.



ODEON automatically saves all required files in the same output folder, which you can either store locally or online. This folder can easily be shared with anyone and it does not need an ODEON license to be explored. The audio files are compressed to the MP4 format for reasonable storage space.

Note: go to Options>Program setup, Auralisation tab for additional settings (output bitrate, choosing to export mixes, convolutions or both).

Overview of the Soundscape app

The Soundscape app is essentially an HTML page, which can be opened in any web browser (computer, tablet or smartphone). If the files are stored locally, you do not need an internet connection to open it. In this page, you can browse through different auralisations produced beforehand in ODEON.
The top banner makes it possible to switch between auralisation modes (Binaural, Surround, as defined in ODEON's Auralisation Setup) and to display either single convolutions or mixes.

In the **Settings** section, a series of dropdown buttons makes it possible to switch between different auralisation scenarios, which have been precalculated in ODEON:

- **Select Material Setup:** switch between different material configurations, as saved in the material list archive in your ODEON project. Read Section 4.4 for more information on the material archive.
- **Select Receiver:** listen to the room from different positions and/or different orientations.
- **Select Signals/Source(s):** test your auralisations with different signals and/or different source positions.
- **Select Soundscape:** the list contains all the auralisations exported from ODEON (single convolutions or mixes, depending on which page you use). The convolutions and mixes are receiver and signal dependent, so changing this item will also update the Signal and Receiver fields.

The logic for browsing through auralisations is the same as in the 360Auralisation tool in ODEON. You can read more about it in the previous subsection.

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The page also contains a screenshot of the 3D render that shows the point of view of the currently selected receiver.

Preparing the auralisations in ODEON

We recommend anticipating which auralisation scenarios you want to export, in order to make the interface of the Soundscape app as clear as possible. Possible comparisons include the following:

- **Different material configurations**, e.g., with and without acoustic panels (note: for each material configuration, all convolutions are recalculated).
- **Different input signals** (e.g., speech vs. music).
- **Different source positions.**
- **Different receiver positions** (e.g., experience the sound in an auditorium at different seats).

Then, the workflow to export auralisations is as follows:

- Create the desired jobs in ODEON:
  - Add the proper sources and receivers in the list
  - Define the different material configurations in the material list, using the material list archive . Check Section 4.4 for more information.
  - Set up the desired auralisation output(s) in the Auralisation setup . Follow our guidance in Section 7.3.
  - Set up the auralisations in the Job list (either manually or using the multi-source auralisation expert), as explained in Section 7.4.
- Run batch calculations in ODEON, by clicking on .
- Select an output folder: all relevant files will be saved in that folder.
- ODEON creates the HTML pages automatically, as well as audio files and screenshots of the 3D Render at each receiver position. Single convolutions and mixes are handled separately and result in two different HTML files. Note: calculations may take a while!
- The HTML files are automatically opened in your default web browser, but you can always find them at the output folder location later on.
- If you want to share the auralisations, you should include all files contained in the output folder.

7.6 Movie auralisation

Movie Auralisation enables you to create a video file of an auralisation in the MP4 format, in which the receiver is moving on a predefined path within a room model. The visuals are taken from the 3D Render.

The overall workflow is as follows:

- Create a mix, as currently done for multi-source auralisations.
- Create one or several receiver paths.
- Generate a movie file for a selected receiver path and a mix.

Access

The Movie Setup menu is accessible in the Auralisation tab of the Job List . Click on .

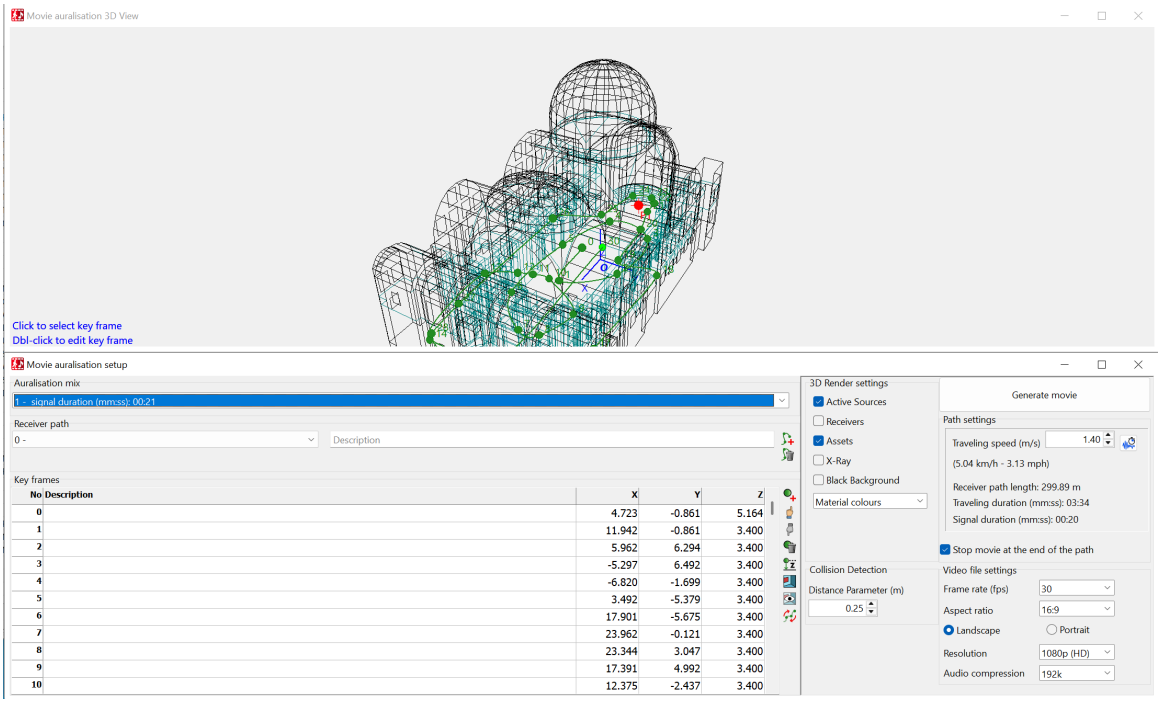
We recommend first creating mixes in the auralisation list, in the same way as the previous versions of ODEON, see Section 7.4. You will have to specify a receiver in the mix, but it will not be used in the creation of the movie. Similarly, recording levels do not matter for movie auralisations.

Note: the tool only works for mixes at the moment, not single convolutions. If you want to create an auralisation with a single source, you should create a mix that contains only one convolution.

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Interface

The interface is similar to other menus (Source-Receiver list, Material list), in which the lower part shows various data and the upper part shows a 3D View of the room with the paths. Paths are updated in real time, either directly in the 3D View or in the setup window below.



Receiver path

The main part of the movie auralisation setup is to create a receiver path, which corresponds to the path the receiver will follow in the movie output. Each path consists of a set of points called key frames, which are defined by the user. It is possible to create and browse through several paths.

Note: a current limitation is that a receiver path requires at least 3 key frames to be valid. If fewer key frames are defined, the path will not be displayed. In addition, if two consecutive key frames have exactly the same coordinates, the second one will be ignored.

Key frames

The receiver path is composed of key frames. An interpolation algorithm creates a smooth line that passes through every key frame. The main part of the key frame section is a table in which you can edit the key frames, in terms of coordinates.

Note: in ODEON 19, you cannot set the orientation of key frames. The orientation will be defined by the path, as the receiver will always be facing in the direction of the path.

The key frames menu contains the following buttons:

- Add key frame .
- Move key frame up or down .
- Remove key frame .

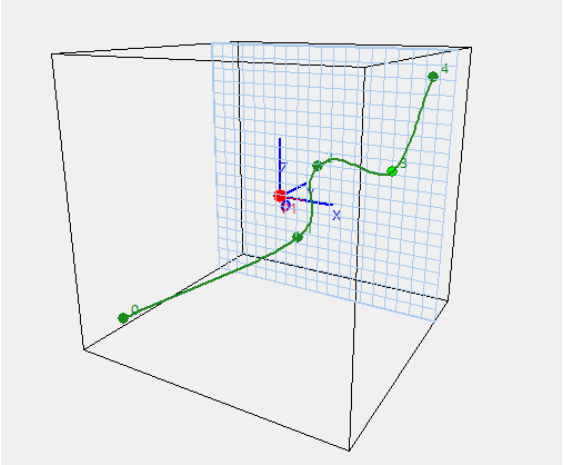
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- Align X, Y, Z relative to surface : this is the same function as the one defined for sources and receivers. A typical example is to ensure that the key frame is at a known distance from the surface directly below it.
- 3D Render view from key frame opens a 3D Render window at the position of the selected key frame. You can use the 3D render to reposition the key frame.
- Video preview opens a 3D render window that follows the receiver path. This tool is useful to check how the video output will look like.
- Reverse key frame order : this button reverses the list of key frames. The first key frame in the list becomes the last and so on.

3D View

The 3D View shows a display of your room, together with your selected receiver path and its key frames, drawn as green circles. The usual 3D view navigation options are available. The receiver path is only displayed if it is valid, i.e. it contains at least 3 key frames. It is updated in real-time, for every modification made on key frames.

If you double-click on a key frame coordinate in the table or if you double-click on a key frame in the 3D View, you will enter Edit mode, in which you can modify the selected key frame's position. In Edit mode, a grid is available to help you reposition the key frame, in the same fashion as in the source-receiver list. Press Escape to exit Edit mode.



Tip: check the hints on the lower left corner of the 3D view. They show different ways of repositioning a key frame.

3D Render

The movie auralisation setup contains two versions of the 3D render: a 3D render view from key frame, accessed by clicking on , and a video preview that makes you travel through the receiver path . Only one 3D render window can be open at a time.

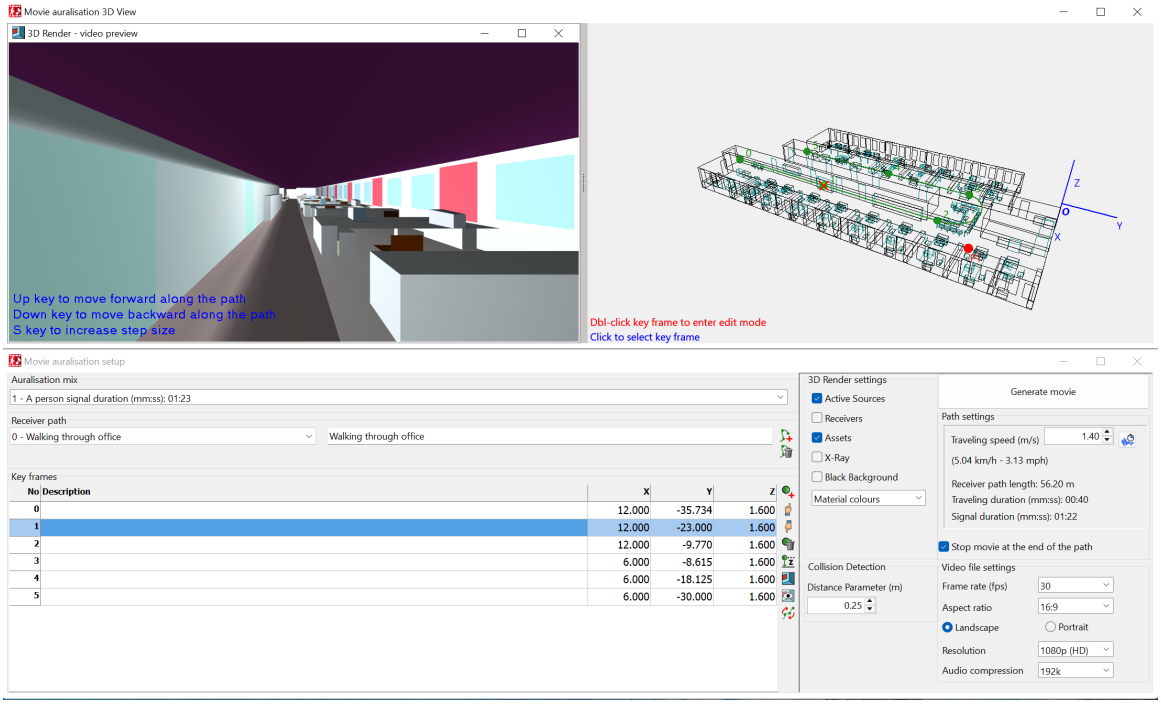
3D Render view from key frame

This 3D render menu shows a first-person view at the selected key frame's position. It is a useful complement to the 3D view, at it shows what you can see from the key frame's viewpoint. You can freely rotate the 3D render view, as no orientation is associated to key frames. The menu can be used to edit the key frame's position: if you change position within the 3D Render, the position of the corresponding key frame will be updated accordingly. Selecting a different key frame will update the 3D render view to the new key frame's position.

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At any moment, the key frame data is consistent between the table, the 3D view and the 3D Render. Any modification in one of these windows will also be visible in the other windows.

Video preview



The video preview is another 3D Render display that allows you to check how the receiver path will look like in the movie output.

The 3D video preview requires a valid receiver path. Therefore, if the list only contains 2 key frames, you will be asked if a new key frame should be added in between the two existing key frames.

To avoid confusion with the other 3D render (view from key frame), a large red dot indicates that the active 3D render is the video preview. It may take a few seconds for it to be displayed.

The Video preview includes the following options:

- Up and Down arrows make the view navigate through the path. A red cross is shown on the 3D view to indicate the current position.
- The S shortcut toggles between a “fast” and a “slow” mode (update rate).

Clicking on a key frame either in the 3D view or in the table will bring the video preview position to the selected key frame. While navigating the path, passing by a key frame will select it in the 3D view and the table.

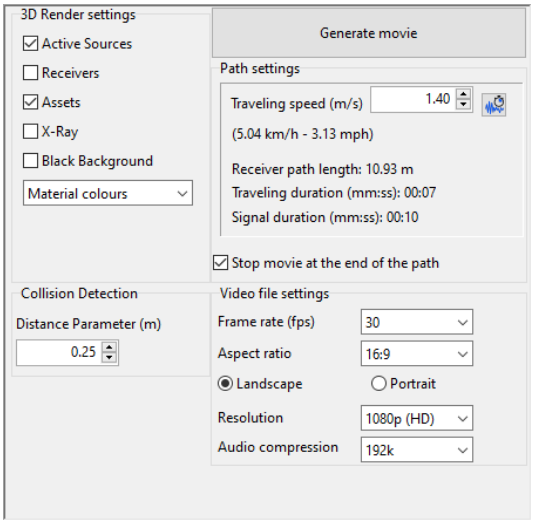
Collision detection is activated by default and will warn you when the path is too close to a surface. You can adjust the collision detection margin in the settings in the lower panel. Similarly, if the path goes outside of the model’s limits, a warning is also triggered.

When the video preview is open, it is not possible to change receiver paths or edit the path in any way. If you make any changes, the video preview will turn into a 3D Render view from key frame.

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Additional settings

Additional settings are found on the **lower right part** of the interface.

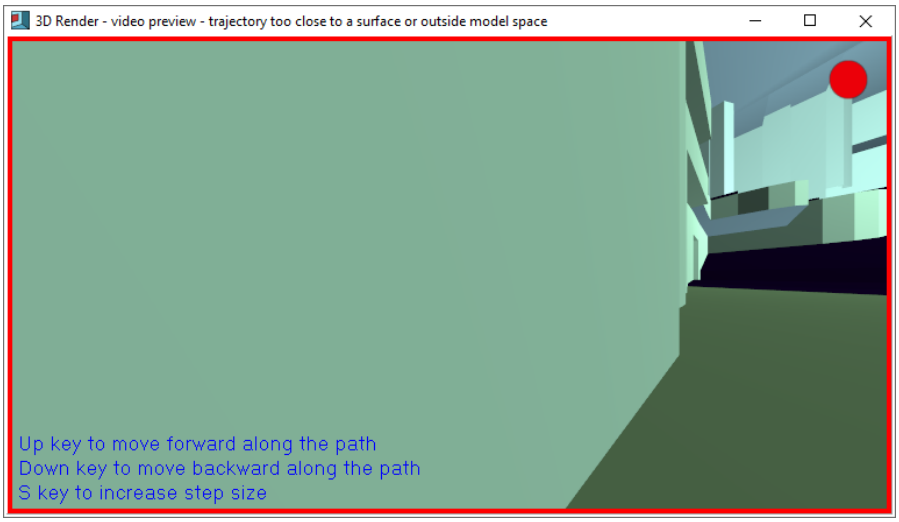


3D Render settings

The 3D Render settings options define how the 3D Render will look like in the video output. If you open a 3D Render within the setup, the display also uses these options. However, you are then free to modify them in the context sensitive menu. This will not change the 3D Render settings.

Collision detection

This section contains a collision detection parameter, which is used in either 3D Render window. If the viewpoint is at a shorter distance to a surface than this parameter, the 3D Render will show you a warning.



Path settings

The path settings section mainly concerns the traveling speed of the path. The default speed, 1.4 m/s, corresponds to a typical walking speed. The speed remains constant along the whole path. The speed is also displayed in km/h and mph for convenience.

Note: the traveling speed is limited to 10 m/s.

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Below the traveling speed, you can read both the traveling duration (depending on the receiver path and the traveling speed) and the signal duration (from the chosen mix). It is useful to compare these two durations, as ideally, they should be similar. If the signal duration is shorter than the traveling duration, the video will stop at the end of the signal, even if you didn't reach the end of the receiver path.

The button adjusts the traveling speed so that the traveling duration and the signal duration are the same.

Stop movie at the end of the path: if this option is checked, the video will stop at the end of the path, even if the signal is not finished. If unchecked, the rest of the signal will be played at the end of the path. The receiver will then be immobile.

Video file settings

These options concern the output MP4 file.

- **Frame rate:** available rates are 12, 24, 30 (default) and 60 frames per second.
- **Aspect ratio:** choose the orientation of the video first (landscape or portrait). Then a list of typical aspect ratio is available: 20:9, 16:9 (default), 4:3, 3:2 and 1:1.
- **Resolution:** choose between a range of resolutions, from standard quality to 8K. The number corresponds to the number of pixels in the smallest dimension of the video.
- **Audio compression:** the audio in the output video is encoded in AAC. You can select different frame rates from 48 kb/s to 320 kb/s.

Note: the audio has to be encoded and compressed to be read in an MP4 video file. Nevertheless, the compression is not audible for high bit rates.

Creating a movie

Once you have set up your movie auralisation (mix, receiver path, path settings, 3D render settings and video file settings), click on Generate movie and select a file name and location.
The receiver path must be valid for the movie to be created, so it should contain at least 3 frames. If the list only contains 2 key frames, you will be asked if a new key frame should be added in between the two existing key frames.
The movie generation can take a while, and the calculation time depends on your computer's capabilities. Processors with multiple cores are advantageous for the calculation.

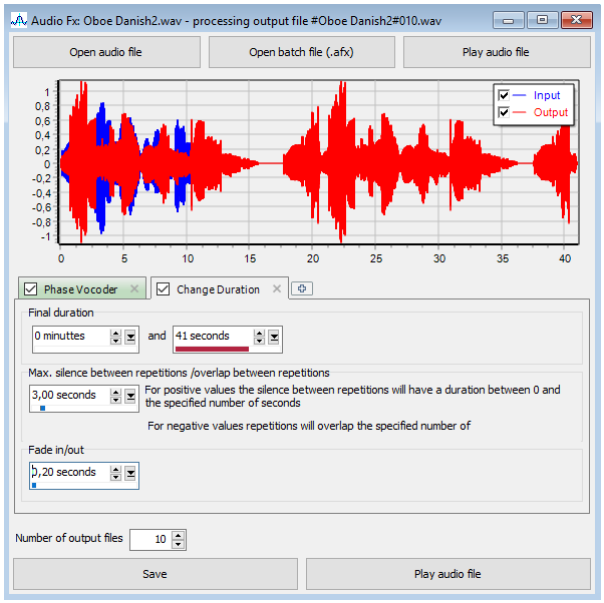


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Current constraints

- **Fixed speed:** we travel through the receiver path at a fixed speed, defined by the user. We recommend a walking speed (about 1.4 m/s).
- **Orientation:** we follow the orientation given by the path.
- Only binaural listening is available at the moment.

7.7 Audio Effects – Multiplying the Audio Files



A common problem experienced when making auralisations is the limited number of appropriate anechoic audio files available. Realistic multi-source auralisations require a large number of recordings (e.g., a cafeteria with many people talking at the same time, or the string section of an orchestra consisting of many violins).
Although many anechoic audio files are available with ODEON, they often need to be manipulated, so that their variations can be assigned to different convolutions of a multi-source auralisation. Cloning and overlaying the exact same audio instead would not provide a realistic effect, due to too much correlation between the signals.
The workflow for creating variations and individual convolutions is explained in (Christensen, et al., 2021).

The *Audio Effects* interface facilitates the generation of many variations from a single audio file. Six effects are currently available: Change Duration, Phase Vocoder, Chorus, Spectrumizer, Gain and Amplitude Modulation.

Traditional audio effects tools aim at making a single fine-tuned variation of an input file, based on some user-defined parameters. However, the purpose of the ODEON *Audio Effects* tool is to make a population of output files automatically, with random variations of the associated parameters. Some of the files created by the tool might sound unrealistic when played individually, but it is not a problem when all the files are played together.

Note: All the effects come with some pre-defined parameters, that have been finetuned by the ODEON team, after long and repeating listening sessions. However, every multi-source auralisation scenario is different, and therefore it is worth trying different settings.

It is possible and often desirable to use multiple effects on the same input – though you will probably not be using all effects at the same time. For string instruments, it is useful to apply the Chorus as well as the Spectrumizer effects to simulate *different players* playing on *different instruments.* For voice samples to be used for crowd simulations, it is often desirable to use the Change duration and Phase Vocoder effects to create outputs that are *incoherent and with a desired duration* and voices of *different pitch and tempo.*

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The output files from the Audio FX tool are created in the selected folder and are assigned a number in their name (e.g., FileName#1). They can easily be implemented in multi-source auralisations using the Auralisation Expert . See Section 7.4 for more information.

How to Use the Audio Effects Tool

The Audio Effects tool is located at Tools>Audio Effects. You can find a step-by-step guide in our video tutorials, on how to simulate a full violin section and how to create realistic crowd auralisations. For additional information, in particular on the parameters of every audio effect, you can visit ODEON's help by pressing F1.

Tip: you can select several files at the same time, if they should be modified with the same effects (e.g. creating a population of speech signals out of several original ones).

List of Audio Effects in ODEON

The *Audio Effects* tool currently includes six effects. Their implementation is explained in details in (Christensen, et al., 2021).

Change Duration

The Change Duration effect changes the overall duration of an input file, either by adding repetitions and silences between them (longer duration) or by cropping it (shorter duration); it does not alter the pitch or speed of the signal. This effect can be useful in creating scenes and soundscapes containing multiple speech signals, music, noise events etc., which will typically require that the input signals to the multi-source auralisation have the same length.

The user determines the final duration of the file, the length of silence (or a range of random silences) between repetitions and the length of fade in/out for the whole output signal. The effect is mostly useful for creating a population of output files with a longer final duration and random variations of silence between them.

Phase Vocoder

A common way to change the pitch of a signal is by resampling it in the time-domain. For example, when a signal is downsampled (fewer samples per second), then the pitch rises, but at the same time the duration becomes shorter (higher playback speed). On the other hand, if the signal is upsampled (more samples per second), then the pitch becomes lower, but the duration becomes longer.

However, it is often desirable to change the pitch and speed independently. The Phase Vocoder belongs to the time frequency processing audio effects and among others, it offers that particular function. It can be used for example to make a speech signal slower without changing its pitch.

The effect transforms the time-domain signal into a time frequency-domain representation, where its *Magnitude* and *Phase* can be modified. The modified frequency-domain representation is then converted back to the time-domain output signal.

Chorus

The Chorus effect is the result of multipl0e signals of similar pitch and timing played together and perceived as one. Unlike the classic chorus effect - where one output file is produced, the chorus effect in ODEON produces a separate audio file for each signal in the group. To achieve a more realistic variation of pitch and timing, the implementation of the Chorus effect in ODEON is based on fractional delay lines (Zolzer, 2011) that have random variations as a function of time.

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Chorus effects occur, e.g., in a string section of an orchestra or a choir of voices within the same vocal range. Although the members of a string section perform the exact same musical piece, there are always slight variations in pitch and timing of musical notes between them.

Spectrumizer

The Spectrumizer makes random changes to the spectrum of the input, similar to an Equalization (EQ) filter. The main input parameter is the Spectral Random fluctuations in percent which is by default 50 %, meaning that the level may be decreased by up to 6 dB at some frequencies and increased by up to 3 dB at some frequencies.

By adjusting the levels in percent, rather than in a dB scale, it is ensured that the average level of an output signal is the same as that of the input signal. This is important for a controlled design of soundscapes.

The effect can be used to alter the timbre of musical instruments. For example, it can help creating variations of the individual string instruments in a string orchestra (violins, violas, etc.). It can be used in combination with the *Chorus* effect to create a full string section from one input file.

Gain

The Gain effect is very simple. It changes the gain by a fixed number of dB.

Amplitude Modulation

The Amplitude Modulation effect changes the amplitude of the signal by a random envelope that is defined between a minimum and a maximum change in dB.

Creating batch files for Audio Effects

The generation of audio files with the audio effects can be automated and parametrised. This is especially useful when you want to save a project as an Odeon Zip Archive with multiple auralisations. You will need to include only the source audio file, and the variations will be recreated automatically when the Odeon Zip Archive is unzipped.

All the parameters are manually written into a text file, with the extension .AFX, which should be saved with the project. You can find more information on the structure and syntax of such a file in the ODEON help menu (F1 key, Audio Effects menu).

7.8 Additional resources

If you want to know more about auralisation in ODEON, you can use the following resources:

- **Contextual help in ODEON:** press the F1 key to access help on the active window.
- **Video tutorials:** visit our webpage on auralisation tutorials. We regularly update our video content to explain new features and applications, so it is a good idea to follow our YouTube channel or our Bilibili page to keep yourself up-to-date.
- **Application notes:** relevant application notes include calibrating sound levels for presentations and Orchestra simulation and auralisation.
- **Publications:** you can find many of our publications in scientific journals and conferences on our Publications page.
- **ODEON Zip Archives:** a series of examples of room with predefined auralisations can be found on the ODEON website. These archives include the complete room model, but also the necessary input anechoic files to create the auralisations. The examples include multiple concert halls, an open-plan office, a cafeteria.

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- **ODEON Files:** many useful room examples and anechoic signals are also provided with the ODEON installation. You can find them in the ODEON folder (by default C:/Odeon[VERSION][EDITION]/, subfolders Rooms and WaveSignals).

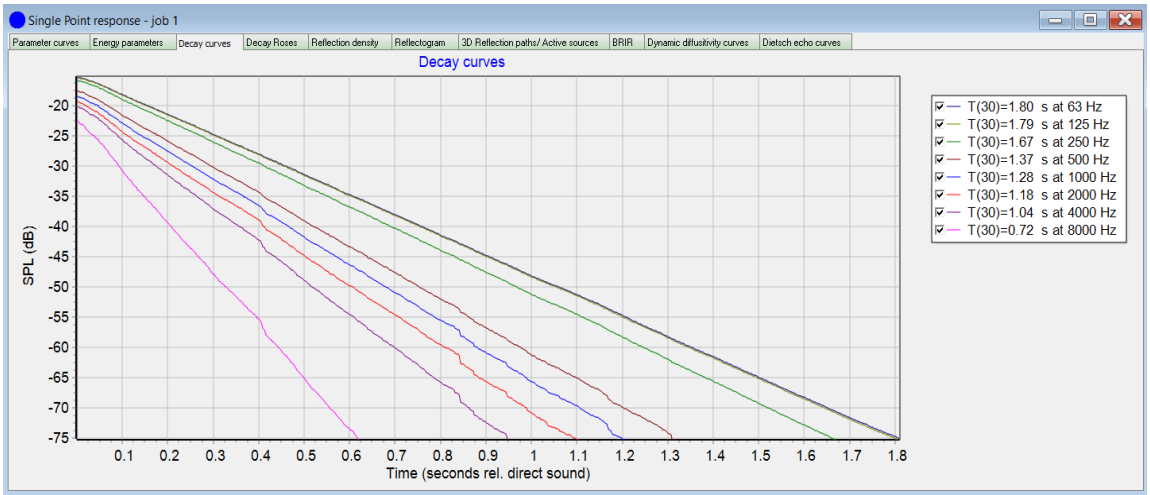
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8 Room Acoustical Parameters

ODEON derives a large number of acoustics parameters from simulations as well as measurements. Many of them are calculated according to the ISO standard 3382, part 1, 2 and 3 for room acoustics, for *Performance spaces*, *Ordinary spaces* and *Open-plan offices* respectively (ISO 3382-1, 2009).
This chapter will shortly describe the most common of these parameters, what they are used for, and the theory behind. This manual will not cover the use of the individual parameters in depth. Recommended values given for the parameters should only be considered as a first suggestion. Besides using the default parameters, since ODEON 11 you can define your own ones or edit existing ones in the Room Acoustic Parameters List .

8.1 Decay curve

Reverberation parameters in ODEON are related to the *decay curve*. This is the curve that shows how sound energy decays in time, after a continuous noise source has been switched off. A *decay curve* is derived from the impulse response, which includes all information regarding reflections and absorption at a particular receiver position. Since each subsequent reflection becomes weaker due to sound absorption from the surfaces in the room and from the air, a decay curve has always a **negative slope**. Decay curves in ODEON are calculated for eight octave bands (63Hz to 8000Hz) separately. The following figure shows an example. Here the overall level, as shown on the left axis, is negative, which simply means that the sound power of the sound source used in this example is very low. For simulations, where background noise is inherently absent, there is absolutely no problem in having very low (e.g.: negative) levels for the decay curves. Since many simulated parameters only depend on the slope of the curves and not the actual levels, results will be reliable. Some room acoustics parameters do rely on 'actual' levels and these will be mentioned explicitly further below.



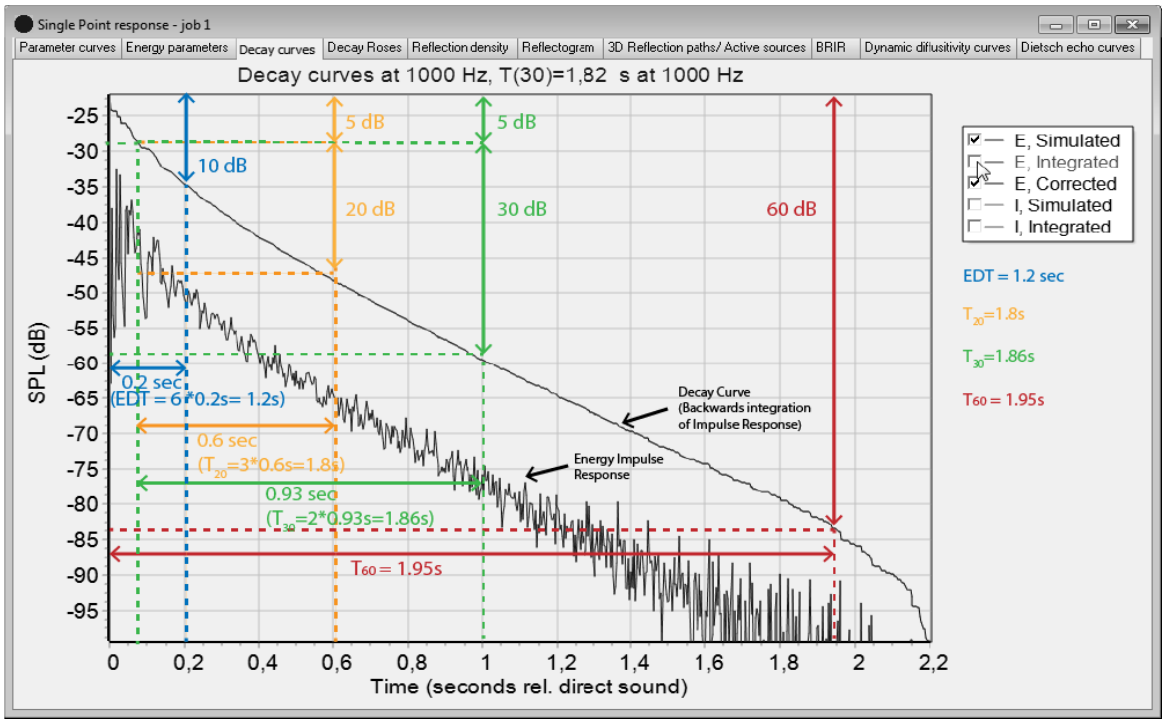
Remember: For reverberation times and many other room acoustic parameters, the actual level of the decay curve is not crucial. The parameters depend on the slope and the shape of the decay. Therefore, even negative dB values are accepted, which is the case if a very weak sound source has been used in the Source-Receiver list (e.g. the default Omni.SO8 source).

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8.2 Reverberation Time and Early Decay Time

Reverberation time is the most frequently used parameter in room acoustics. Some acousticians rely only on reverberation time when evaluating room acoustics, but for most cases this is not sufficient. The reverberation time is defined as the time it takes for a sound to decay by 60 dB after the sound source has been switched off. This is noted as T_{60}.
The most common experience of reverberation time in a space is when making a fast hand-clap. This corresponds to a loud sound source which has been 'turned on' and 'off' almost momentarily, leaving a decaying tail of sound which often takes one or a few seconds to cease. Reverberation time can reveal information about the size of a room and absorption in a room. Large rooms with sound reflective surfaces have longer reverberation times, while small rooms with sound absorptive surfaces have short reverberation times.

When measuring reverberation time in practice there is always a considerable level of background noise in the recording (ambient acoustic noise, electric noise in microphone, electronics, cables, etc.) which reduces the range of 60dB required to derive T_{60}. Therefore, reverberation time is calculated based on smaller decay ranges (10 dB, 15 dB, 20 dB and 30 dB) instead, which are well above the background noise level. **However, the corresponding time it takes for each decay range is always multiplied by an appropriate factor to extrapolate the time for 60 dB decay**. Calculating reverberation time in this way results in multiple different numbers for reverberation time: The following graph shows the process:



- *Early Decay Time* (EDT) is obtained from the initial 10 dB drop of the backward-integrated decay curve, by applying the best-fit linear regression line between 0 and -10 dB. Assuming that decay is linear, extrapolation of 10 dB range to 60 dB requires multiplication by 6. In the example above, the time elapsed for 10 dB decay is 0.2 s. Therefore EDT=6*0.2=1.2 s.
  Early Decay Time has to do with the early sound reflections only. If a sound source is continuous, e.g. speech or music, a lot of the reverberation of a sound incident will be masked by the next sound incidents. Thereby the late part of the reverberation will become unnoticeable. Early decay time is related to the first -10dB and can be a better parameter to investigate the experienced reverberation of continuous sound sources than Reverberation Time is.

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Since the early part of the decay is dominated by the direct sound and it is much steeper than the rest, EDT is usually shorter than the rest type of reverberation times.

- Reverberation time T_{15}, obtained applying the best-fit linear regression line between -5 and -20 dB (not shown in the graph above), and then multiplied by 4.
- Reverberation time T_{20} is similar to T_{15}. The linear regression line is found from -5 to -25dB and then multiplied by 3. In the example above T_{20}=3*0.6=1.80s.
- Reverberation time T_{30} is similar to T_{15}. The linear regression line is found from -5 to -35dB and then multiplied by 2. In the example above T_{30}=2*0.93=1.86s.

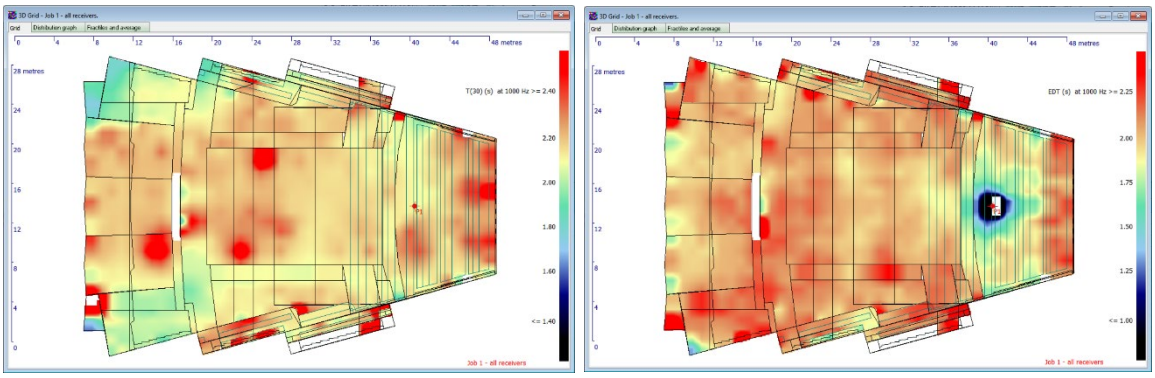
For simple rooms, with evenly distributed absorption, the different values of reverberation times can be very close to each other, since the decay is almost a straight line (in decibels, therefore a logarithmic scale). For coupled spaces and other complex rooms, the decay curve might change the slope through time, therefore reverberation time can be quite different depending in which part of the energy curve has been used for evaluation.

Guidelines for simulating Reverberation time

According to the definitions above, the various reverberation times T_{15}, T_{20} and T_{30} do not take into account the initial part of the response, i.e., between 0 and -5 dB. This means they are not affected by the direct sound from the source, but mostly from the late reflections, which become progressively more diffuse over time. Consequently, we expect that the spatial variation of T_{15}, T_{20} and T_{30} is much smaller comparing to other room acoustic parameters that depend on the direct sound. For example, although EDT is defined as a variation of reverberation time, its behaviour is much different than the rest reverberation times. Since it is evaluated between 0 and -10 dB on the decay curve, it is heavily affected by the direct sound and the early reflections, so that its fluctuations throughout the space are significantly higher.

Spatial distribution

Looking at the following example of grid calculations in ODEON, variation of reverberation time T_{30} in a regular volume is not as big as of Early Decay Time (EDT).



Left: Grid calculation of T_{30} on the floor and audience surfaces at 1000 Hz. The values vary mostly between 1.8 and 2.4 sec (app. 0.6 *sec* range). **Right:** Grid calculation of EDT on the floor and audience surfaces at 1000 Hz. The variation is greater, between 1 and 2.25 sec (app. 1.25 *sec* range).

Reverberation time is considered a global parameter, which means that it is highly affected by the room as a whole and not by local reflections. Therefore, it is preferred to be reported as an average over a number of source-receiver combinations, instead of specific receiver locations. The standard provides suggestions for the number of sources and receivers to be included in the averages, according to the desired level of precision in the simulations (or measurements).
The ODEON's Multi Point Response in the Joblist (see Section 5.2), is probably the best and most handy tool to simulate or measure reverberation time, according to (ISO 3382-1, 2009) and (ISO 3382-2,

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2008). You can use other simulation tools, like the Global Estimate (see Section 5.1) or the Grid Response, but none of them can be entirely consistent with the standard, as will be seen further below.

Remember: It is generally not recommended to report reverberation times T_{15}, T_{20} and T_{30} at specific receiver positions, but as an **average** obtained from several source-receiver combinations.

Source-receiver positions

According to (ISO 3382-2, 2008) the sources can be located at a normal position of human speakers, loudspeakers etc. according to the expected use of the room. In small rooms such as domestic rooms or when no normal positions exist, one source position should be in a corner of the room.

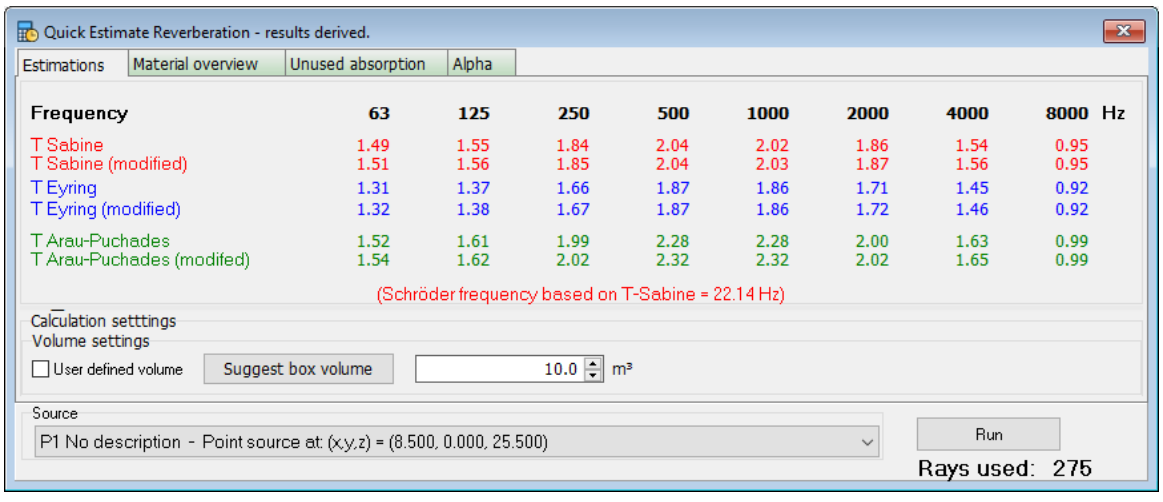
- Receiver (microphone) positions should preferably be at least **half a wavelength apart**. For frequencies above 63 Hz, this corresponds to 2.7m. However, considering that the frequency range for speech starts from 125 Hz, this distance becomes 1.4m. That is why the standard gives the sugge stion of **2m for the usual frequency range**.
- The distance from any receiver position to the nearest reflecting surface, including the floor, should be at least a quarter of a wavelength, i.e. around **1 m for the usual frequency range**.
- Symmetric positions should be avoided.
- The receiver should be at the following minimum distance (in meters) from the source:

$$d_{min} = 2\sqrt{\frac{V}{c\widehat{RT}}}$$

The formula is particularly useful for measurements and not simulations. If we use the simplified Sabine equation that relates reverberation time with volume V and absorption area A, $RT = 0.16A/V$, we can rewrite the formula for minimum distance as:

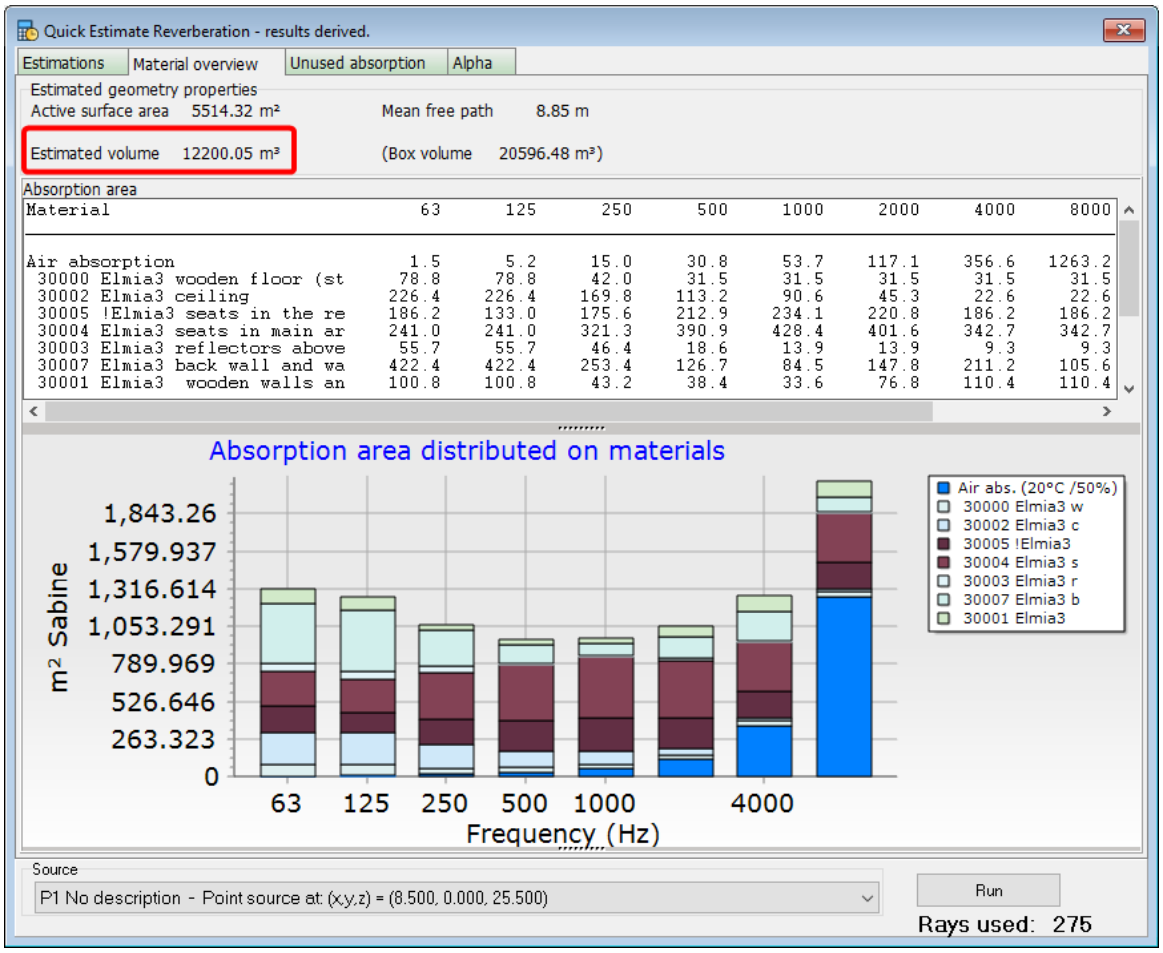
$$d_{min} = 2\sqrt{\frac{A}{0.16c}}$$

where V is the volume of the room in m^3 and $\widehat{RT}$ is an estimation of the expected reverberation time in *sec*. Both values can be easily obtained from the Quick Estimate in the Material list.



Obtain *RT* from Quick Estimate. The reverberation times given from *Sabine* and *Eyring* formulas provide a sufficient estimation for calculating the minimum distance between source and receivers. These values are calculated based on the source location (at the bottom of the window), but the variation is minimal. It is only used by ODEON to detect the volume, where the source is located, to ensure that surfaces from other potential coupled volumes are excluded from the calculation. See more in Section 5.1.

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Obtain *V* from Quick Estimate. The second tabsheet of the Quick Estimate window provides a sufficient estimation of the room volume, which can be used when calculating the minimum distance from the source.

According to the guidelines above, neither the Global Estimate or the Grid Response in ODEON satisfy all necessary distances between sources, receivers and reflecting surfaces. The Global Estimate provides calculation for the entire volume of the space (not only close to the human-receiver height), while the Grid Response - although it can be set at a realistic height - can include receivers too close to the source or walls. Therefore, both types of calculation should be use with care. Instead, to have full control over the location of sources and receivers the Multi Point Response calculation should be used.

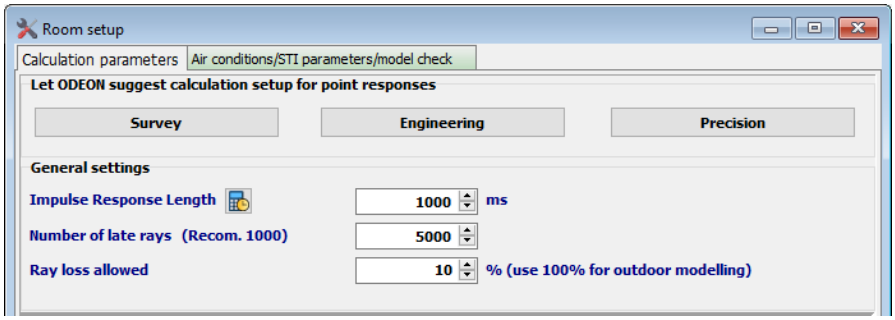
The Table below shows the minimum number of required source-receiver positions, according to the precision desired for the final average of the reverberation time. These numbers are taken directly from (ISO 3382-2, 2008) which has been developed for measurements. We can follow the same guidelines in simulations since the only difference is the lack of ambient (background) noise. the lack of ambient noise can only improve the simulation results.

	Survey	Engineering	Precision
Source-receiver combinations	≥2	≥6	≥12
Number of sources	≥1	≥2	≥2
Number of receivers	≥2	≥2	≥3
When the result is used for a correction term to other engineering-level measurements, only 1 source-position and 3 microphone-positions are required.			

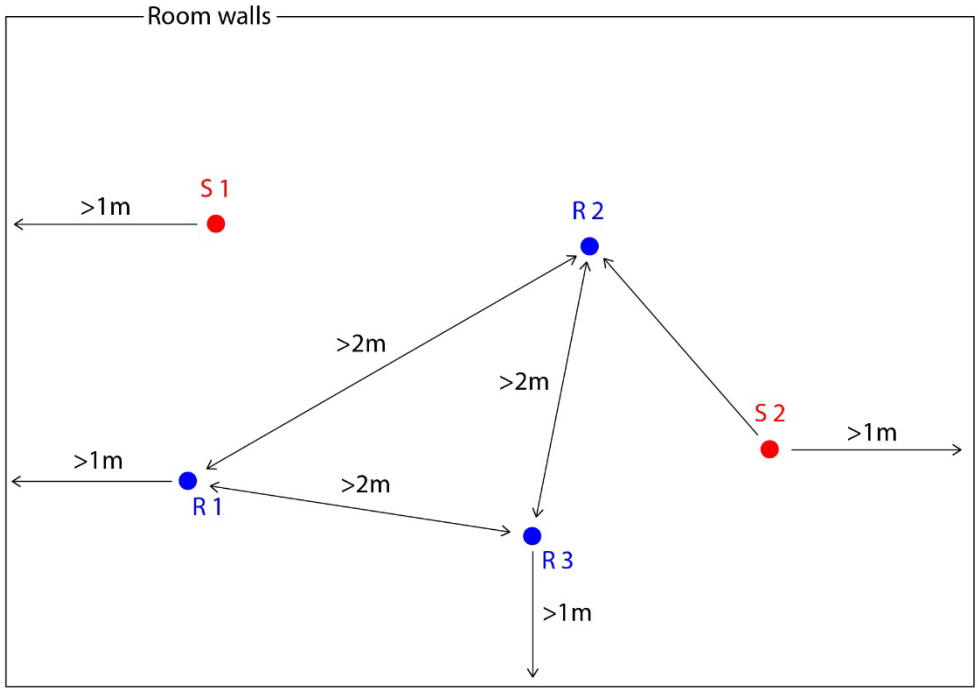
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Several source-receiver combinations must be included for each of the three levels of accuracy. There is freedom to choose how many sources or receivers to include in the combinations, but the minimum number of each must be respected. For example, for a minimum of 12 combinations in the Precision method only the following cases can be acceptable: 2 Sources – 6 Receivers, 3 Sources – 4 Receivers, 4 Sources – 3 Receivers.

We apply the same principles in ODEON simulations, and therefore the Room Setup has been equipped with the buttons Survey, Engineering and Precision, in order to make the connection to the measuring standard. However, these settings only affect the calculation parameters such as the number of rays and not the number of sources or receivers. They are used as an indication of simulation accuracy. See more about the different parameters in the room setup in Chapter 10.



In the following picture an example of Engineering calculation is illustrated with 2 Sources and 3 Receivers, with some of the critical distances indicated.



Example of engineering calculation with 2 sources and 3 receivers. All distances from the nearest walls are >1m and all distances between receivers are >2m. The minimum distance d_{min} between source and receiver ensures that the receiver is not in the near field of the source, but in the reverberant field. Thus, it is not heavily affected by the direct sound.

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Occupancy state

In many rooms, the number of people present can have a strong influence on the reverberation time. On a general basis, reverberation time measurements and simulations should be made in a room without people. However, the absorption from people can always be included if it is necessary for a particular simulation, as long as it is clearly written in the report. Specifically for performance spaces, the ISO standard (ISO 3382-1, 2009) defines three states of occupancy that can be used as a reference.

Unoccupied state
State of a room prepared for use and ready for speakers or for performers and audience, but without these persons being present, and in the case of concert halls and opera houses, preferably with the performers' seats, music stands, heavy instruments (percussions, piano etc.) and generally any immobile equipment.

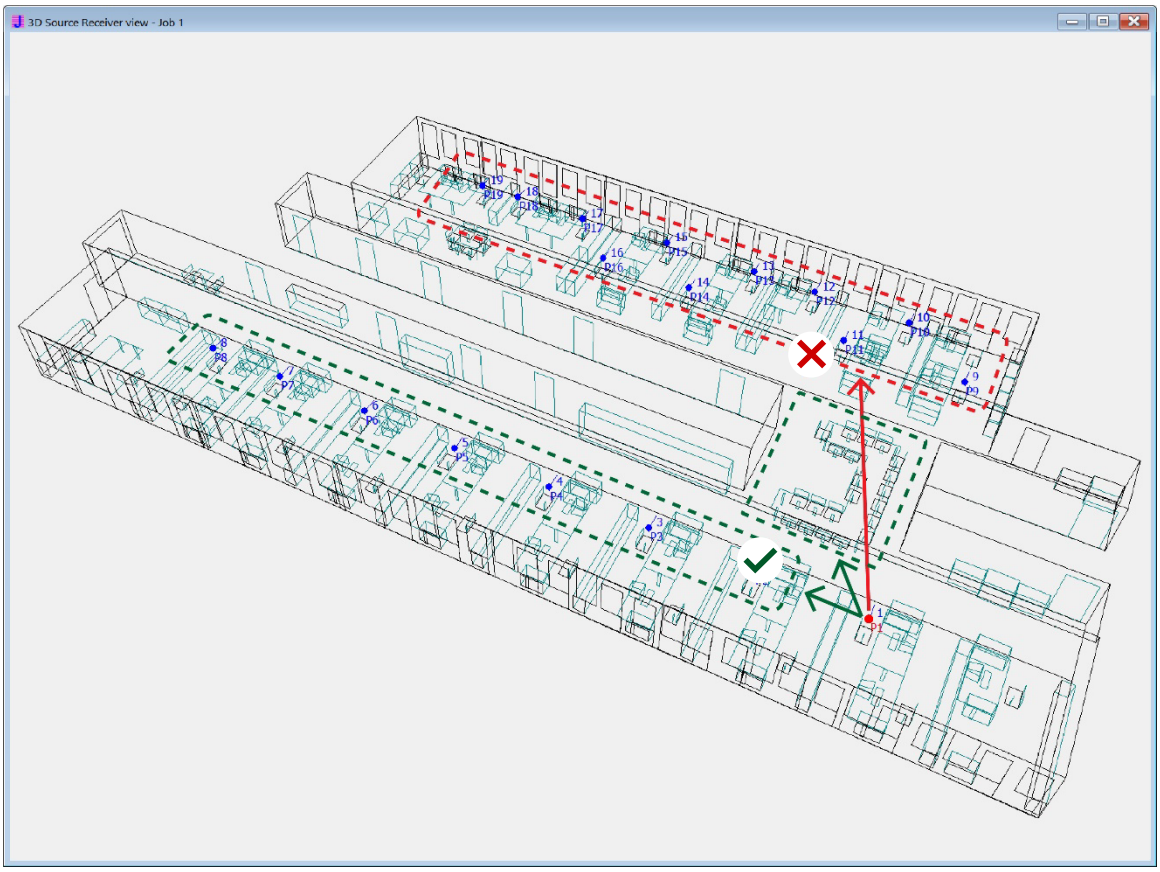
Studio state
State of a room occupied by performers or speakers only and without an audience (for example, during rehearsals or sound recordings) and with the number of performers and other persons such as technicians corresponding to the usual number.

Occupied state
State of an auditorium or theatre when 80 % to 100 % of the seats are occupied by audience. In cases of extraordinary occupancy (for example an orchestra larger than usual, or a choir/standees are present), the extra absorption introduced shall be included in the simulations.

Coupled volumes

Often, spaces are connected via corridors or openings, and although they are not physically fully separated by walls or doors, it is not recommended to study them as one volume. According to (ISO 3382-1, 2009) such coupled spaces are likely to show areas with differing reverberation times. Therefore, they must be investigated and measured separately. In other words, both sources and receivers must be inside the same space. There is not much benefit in having the source in one of the coupled spaces and the receiver in the other.
In the following open-plan office example we can identify two large spaces, connected via a smaller one. The source is located at the lower space. The most correct calculation/measurement of reverberation time would be at the receiver positions marked by the dashed-green rectangle, while the least correct would be at the receiver positions marked by the dashed-red rectangle at the upper space. Calculating reverberation time in the *middle space* would also be acceptable and accurate enough, as the common opening is relatively large comparing to the volume of the space. Moreover, there is direct contribution from the source inside the *middle space*, which makes the decay response quite accurate.

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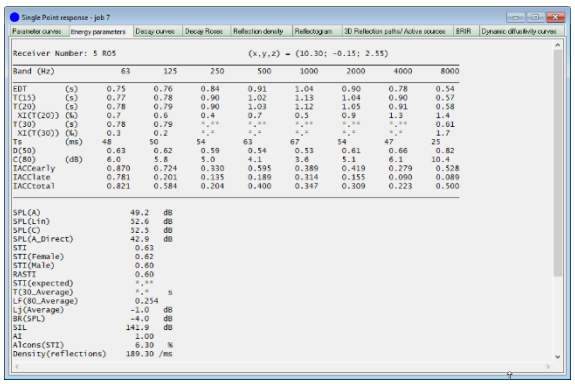
When simulating/measuring reverberation time in coupled spaces, make sure the source is at the same space as the receivers, and try to split the calculation for the different spaces. Adjacent spaces, with large connecting openings with the main space can be included at the same calculation. In the example above, with the source located at the lower space it makes sense to calculate reverberation time around the areas marked with the dashed-green rectangle.

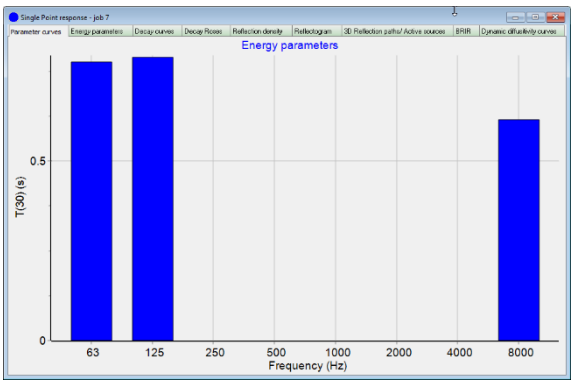
Impulse Response Resolution

The energy of all the reflections received at the receiver point is collected in histograms in regular time intervals, which are specified in the Room setup>Impulse response resolution. After completion of the response calculation, early decay time and rest reverberation times are calculated according to the procedure described above.

Problems calculating Reverberation Time

Many times reverberation time fails to be calculated, leaving *.** values in the Energy Parameters tab sheet or empty bars in the Parameter bars tab sheet.





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Warning: The most common reason for failing to obtain results is that the impulse response length in the calculation is too short. Try going to Room setup |Impulse response length and make it longer. Typically, 2/3 of the expected reverberation time is enough.

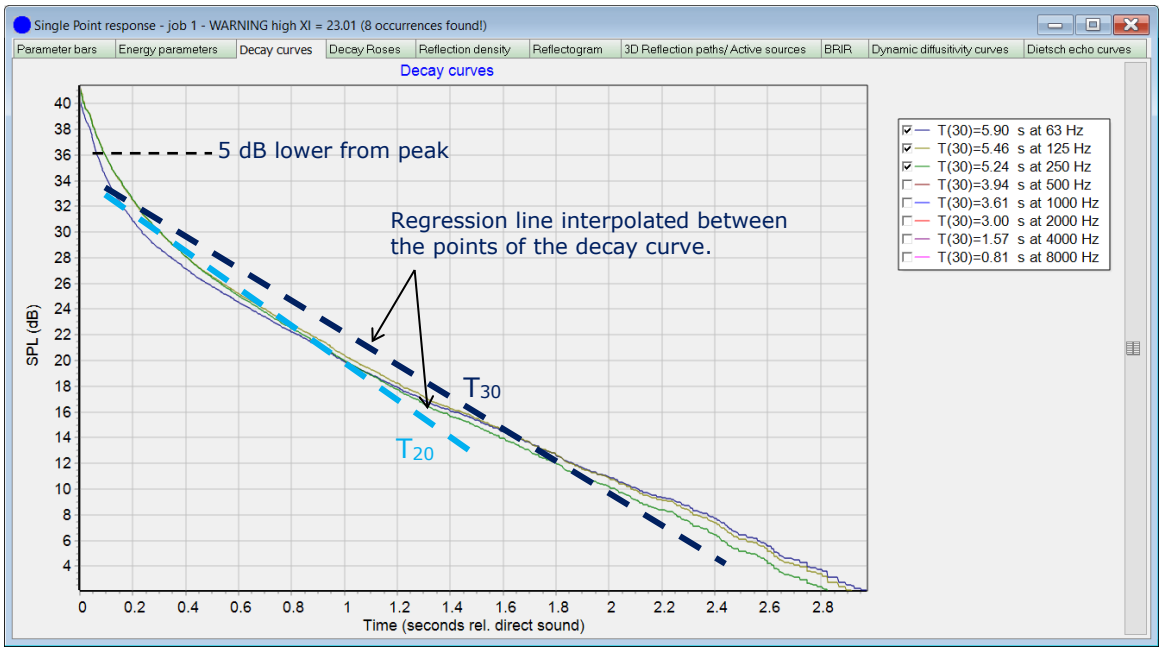
Another problem can be number of late rays. If the room is complex, consists of coupled spaces or is outdoor, there will be a need for a higher number of rays. Go to Room setup |Number of late rays and increase it. You can always look at the Decay curves to evaluate if there are enough rays. A smooth slope means enough rays, where one with drastic drops could be a sign (though, not necessarily) of too few rays.

Curvature, C

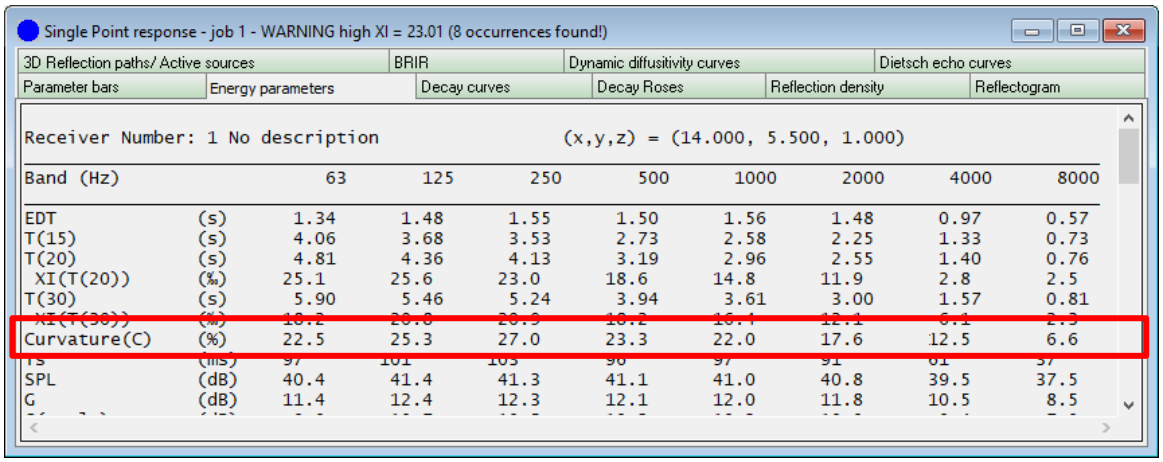
Curvature is an important parameter indicating how straight the decay curve is. It is defined as:

$$C = 100\left(\frac{T_{30}}{T_{20}} - 1\right) \qquad (\%)$$

Ideally, decay curves should be as straight as possible, corresponding to an exponentially decaying, diffuse field. In such a case, T_{20} and T_{30} would be equal and the curvature would be 0. In real life, the decay curve is rarely straight, with the early part being typically steeper than the late part. T_{20} is affected mostly by the early part, while T_{30} by the late. Values of curvature below 10% are perfectly acceptable for most practical applications, while values higher than 15% are not recommended. In such cases, the late part of the decay has significantly shallower slope than the early part, typically because of flutter echoes between parallel hard walls and uneven absorption in the room. The most common example is absorption concentrated on the ceiling, while the walls remain hard. This results in a 2-dimensional sound field (between the parallel hard walls) which is illustrated in the double-slope decay curve. When a high curvature value is present, the number of late rays in the Room Setup needs to be increased dramatically, well above the Precision setting. Otherwise, the results become highly unreliable and values of room acoustic parameters fluctuate with increasing number of rays, until convergence is achieved.
In the following example the bended curve problem is illustrated. The dashed lines roughly indicate the slopes that correspond to T_{20} and T_{30} for the low-mid bands. The calculated Curvature is shown below and it is well above 15%. In this example 22000 late rays were used, instead of the recommended 16000 by the Precision setting in the Room Setup.



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The following table aims to give some general guidelines when evaluating curvature in simulations.

Curvature C(%)	Situation	Number of late Rays needed in the Room Setup	Comments
<10	Acceptable bending of decay curve.	Engineering – Precision setting.	Results are reliable and converge with an increasing number of rays.
10-15	Bending of decay curve starts to become an issue.	At least 2 times the Precision setting.	You need to increase the number of rays beyond the Precision setting to achieve stable results.
>15	Extreme bending of decay curve that should be avoided.	At least 10 times the Precision setting.	Simulations become unreliable and convergence might only be seen after using an enormous number of Rays.

8.3 SPL, G, C_{80}, D_{50}, LF_{80}, ST_{early}, ST_{late} and ST_{total}

Multiple acoustical parameters have been defined through time, to investigate different influences of the room acoustics on the subjective experience of sound. ODEON includes a range of these, and you can add your own based on the same principles. Many of these parameters have to do with sound energy arriving at the receiver positions at different time intervals. For example, the parameter Clarity (C) is based on the fact that for some music and for speech, the sound energy arriving before 50 or 80ms has the most influence on how clearly the sound is perceived, compared to the energy arriving later.

When derived in ODEON the energy of each reflection is added to the appropriate term in the formula of all the energy parameters, according to its time and direction of arrival. After the response calculation, C_{80} (Clarity), D_{50} (Definition), Centre Time, SPL (Sound Pressure Level), LF_{80} (Lateral Energy Fraction), ST_{early}, ST_{late} and ST_{total} are derived.

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Explanation of formulae

Only a few common parameters that are available in ODEON are listed here. You can find the definitions of parameters from within the Room Acoustic Parameter List in ODEON where the formulas are listed, and you can also enter new parameters.

In the following formulae, E_{a-b} is the sum of energy contributions between time *a* and time *b* after the direct sound, time *t* is the end of the calculated response, and β_t is the angle between the incident direction and the axis passing through the ears of a listener, for the reflection arriving at time *t*.
It is worth noticing that parameters relying on the E_{a-b} term assume that time *a* and *b* are well defined - however this is not the case when there is no direct line of sight between source and receiver. It makes results questionable in simulations as well as in real measurements when direct sight between source and receiver is not present.

SPL (Sound Pressure Level)

The SPL is the level of the sound pressure. It is a parameter often used in regulations for e.g. industrial noise levels, since high levels damage hearing. It is also used for regulations on sound levels in living quarters or concerts, for the consideration of neighbours.

When using SPL in ODEON, it is important that the sound source has the correct Sound Power, since an arbitrary Sound Power at the source will give an arbitrary SPL at the receiver positions.
Measurements in real rooms using ODEON will normally give an arbitrary SPL level, because the hardware used is not capable of obtaining exact SPL levels. It can, however, give relative SPL levels compared to each other. When the source power is 31 dB per octave then SPL equals the G parameter (Strength) assuming an omni directional source.

$$SPL = 10\log(E_{0-\infty}) \quad (dB)$$

G (Strength)

The G parameter (Strength) is defined in (ISO 3382-1, 2009). It helps investigate how much the acoustics/reflections of the room contributes the level of the source. In a very reflective space/room there will be a high contribution, in an absorptive space there will be a low contribution. The reference level of 0 dB is obtained in free field at a distance of 10 metres from an omni directional point source. This is obtained by normalizing the Sound Power of an OMNI directional point source to 31dB per octave. Odeon will only calculate the G parameter if the job in Job List:

- Contains only one active source
- The source is a point source
- The directivity file name contains the substring omni (case insensitive)

In this case Odeon will automatically normalize the source power to 31 dB per octave for the calculation of the G parameter(s) – see below.

If you want to measure G using ODEON in a real room, you need to calibrate the measuring system, software, and hardware, using one of the different calibration methods available in ODEON and you should use an omni directional source.

G_{early} and G_{late}

G_{early} and G_{late} are two additional strength parameters used in auditorium acoustics to see how much the room contributes to the early and late part G. The early G includes the energy arriving

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within the first 80 ms and the late G the energy arriving after the first 80 ms, relative to direct sound. Details given for the G parameter also apply to G_{early} and G_{late}.

C_{50} , C_{80} and C_7 (Clarity).

Early reflections arriving before 80 ms after the direct sound contributes to the clarity of symphonic music whereas sound arriving after 80 ms has a "blurring" effect. The (ISO 3382-1) states that C_{50} is appropriate for speech and C_{80} for music. It should be noted that much acoustical research has been made for classical music, but for rhythmical music (pop, rock, etc.) it may not apply in the same way. C_{50} investigates the relation between sound energy before and after 50ms. For C_{80} it is 80ms. ODEON also includes C_7, a parameter that investigates the relation between what may be expected to be direct sound (before 7ms) compared to reflections. The C_7 is mainly for measurements, since direct sound in simulations will be theoretically ideal and will arrive at 0s.

$$C_{80} = 10\log\left(\frac{E_{0-80}}{E_{80-\infty}}\right) \quad (dB)$$

D_{50} (Definition)

Definition is very close to being the same as clarity, but both exist due to historical reasons.

$$D_{50} = \frac{E_{0-50}}{E_{0-\infty}}$$

T_s (Centre time)

Relates to perceived definition, clarity, or the balance between clarity and reverberance, as well as to speech intelligibility.

$$T_s = \frac{\sum_{0}^{\infty} tE_t}{E_{0-\infty}} \quad (ms)$$

LF_{80} (Lateral Energy Fraction)

LF is a parameter for the spaciousness of the room. A room is acoustically very spacious if it makes a sound source be perceived as "wider".

$$LF_{80} = \frac{\sum_{t=5}^{80} E_t \cos^2(\beta_t)}{E_{0-80}}$$

The LF_{80} parameter has a high correlation with the apparent source width (ASW) as shown in (Bradley, et al., 1995).

L_j (Average)

This parameter is suggested in (Bradley, et al., 1995) and is included in (ISO 3382-1, 2009). Lj(Average) has a very high correlation with the subjective parameter Listener envelopment (LEV).

$$Lj(Average)_{80}^{\infty} = 10\log\left[\frac{1}{4}\sum_{N_{125Hz}}^{N_{1000Hz}}\sum_{t=80}^{\infty} E_t \cos^2(\beta_t)\right] \quad (dB)$$

An alternative name for this parameter could have been "Late Lateral G", because the level is normalized in the same manner as for G, G_{early} and G_{late} . Details given for the G parameter also applies to Lj.

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Example of target values

Depending of the purpose of a room, the target values for the acoustical parameters will be different. Auditorium acoustics as in Concert Halls, Opera Halls, Multipurpose halls, etc. are dealt with in (Beranek, 1996) and (Barron, 1993), where halls from all over the world are presented along with a judgement of their acoustics, supplied by a guideline for design. Short guidelines on values for Clarity and G in concert halls, based on some simple design parameters such as width, height, floor-slope, etc. are given in (Gade, 1997). Below some recommended values for room acoustical parameters are shown:

Objective parameter	Symbol	Recommended (symphonic music)	Subj. limen
Reverberation time	T_{30}	1.7 - 2.3 seconds	5 %
Clarity	C_{80}	- 1 to 3 dB	1 dB
Level rel. 10 m free field	G	> 3 dB	1 dB
Early Lateral Energy Fraction	LF_{80}	> 0.25	5 %
Early Support	ST_{early}	> -13 dB	
Total Support	ST_{total}	> -12 dB	

Recommended values for objective room acoustical parameters **(ISO 3382-1, 2009)** in large music rooms with audience, according to Gade **(Gade, 2003)**. Subjective limen as given by Bork **(Bork, 2000)** and Bradley **(Bradley,**

8.4 Stage Parameters

Stage parameters refer to how the acoustics influence the experience for the musicians playing on a stage. The relation between the direct sound and reflection from the surfaces affects how well can they hear themselves and each other.

The parameters are called Early, Late and Total Support, and are described more thoroughly in (Gade, 2003):

Stage parameters are calculated as a part of the Single Point response (Auditorium and Combined versions only). If the job only contains one active source, the active source is a point source and the distance between receiver and source is approximately 1 metre (0.9 to 1.1 metre).

Early Support or ST1:

ST_{early} or ST_1 is used as a descriptor of ensemble conditions, i.e. the ease of hearing other members in an orchestra.

$$ST_{early} = \frac{E_{20-100}}{E_{0-10}} \quad (dB)$$

Late Support:

ST_{late} describes the impression of reverberance.

$$ST_{late} = \frac{E_{100-1000}}{E_{0-10}} \quad (dB)$$

Total Support:

ST_{total} describes the support from the room to the musician's own instrument.

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$$ST_{total} = \frac{E_{20-1000}}{E_{0-10}} \quad (dB)$$

8.5 IACC – Inter-Aural Cross Correlation

Since the hearing process is binaural, the spatial impression in a concert hall can be quantified by measuring the inter-aural cross correlation between the left and right ear canal (ISO 3382-1, 2009).

IACC in math

The Inter-Aural Cross Correlation is expressed as a coefficient from 0 to 1. First, the normalized inter-aural cross correlation function is calculated:

$$IACF_{t_1,t_2}(\tau) = \frac{\int_{t_2}^{t_1} p_l(t) \cdot p_r(t+\tau) dt}{\sqrt{\int_{t_2}^{t_1} p_l^2(t) dt \int_{t_1}^{t_2} p_r(t) dt}}$$

where:

$p_l(t)$ is the impulse response at the entrance to the left ear canal.

$p_r(t)$ is the impulse response at the entrance to the right ear canal.

Then, the inter-aural cross correlation coefficient is calculated as:

$$IACC_{t_1,t_2} = \max \left| IACF_{t_1,t_2} \right| \text{ for } -1\,\text{ms} < \tau < +1\,\text{ms}.$$

IACC in ODEON

To simulate IACC in ODEON you need a virtual dummy head. Therefore, these parameters are only calculated as part of the Single point response. In order to calculate IACC correctly a neutral dummy head without localization enhancement is needed. To create a new HRTF filter without localization enhancement:

- Open Tools > Create filtered HRTF.
- Choose Subject_021Res5deg.ascii_hrtf.
- Press ok (make sure "Apply localization enhancement" is NOT on).
- Go to the "Auralisation setup" in the top-menu bar.
- Checkmark "Create binaural impulse response file".
- For the HRTF choose:
  Subject_021Res10deg_SRate44100_Apass0,50_Astop40,00_BOvrLap100%_PPrHRTF256.
- Delete everything in Headphone (the area will turn red).
- Close window.

If this is something you do often/in many rooms, you can change the default:

- Go to Options > Program Setup.
- Choose Auralisations tab.
- For the HRTF choose:
  ChoosSubject_021Res10deg_SRate44100_Apass0,50_Astop40,00_BOvrLap100%_PPrHRTF256
- Delete everything in Headphone (the area will turn red).
- Close window

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8.6 STI – Speech Transmission Index

To investigate how well speech is understood for a receiver in a room, the Speech Transmission Index, STI, can be used. It is calculated in ODEON according to (IEC 60268-16, 2020).

The calculation of STI is based on studying how modulated signals are transmitted in the room in each octave bands. The STI is calculated for 7 octave bands (125 Hz to 8 kHz) and 14 modulation frequencies (from 0.5 Hz to 16 Hz). This corresponds to 98 modulations in total. Each combination leads to a *modulation transfer function*, describing the loss of modulation due to the room's effect (mainly reverberation). These are then combined and weighted to obtain a single value between 0 and 1.
The STI parameter takes into account the background noise, which may be adjusted from the Room setup. For the STI parameter to be valid, it is very important to adjust the background noise accordingly, see below.

Source directivity

The (IEC 60268-16, 2020) standard does not specify the source directivity or exact spectrum to use when measuring STI. Instead, this should be chosen according to the specific measuring conditions. Following this recommendation for simulations in ODEON as well, it is recommended to use the BB93_NORMAL_NATURAL.SO8 or BB93_RAISED_NATURAL.SO8 sources, when modelling real persons speaking with normal or loud voice respectively (e.g. in auditoria, classrooms or restaurants). Particularly for open-plan offices, the ISO3382-3_OMNI.SO8 source should be used, according to the (ISO 3382-3, 2012). The source is omni-directional but uses the spectrum of a natural voice. For more information about how to choose proper EQ and directivity settings for various situations - including loudspeaker installations, read our application note about STI simulations.

Characterization of STI

The subjective scale of STI is given below:

Subjective scale	STI value
Bad	0.00 - 0.30
Poor	0.30 - 0.45
Fair	0.45 - 0.60
Good	0.60 - 0.75
Excellent	0.75 - 1.00

STI variations

ODEON supports the (IEC 60268-16, 2020), for which **STI_Male** is the main STI parameter. **STIPA** is also widely used, especially when assessing PA systems. **STI_Expected** is a theoretical value that can give you an idea of the STI value from simpler calculations. These three parameters **(STI_Male, STIPA and STI_Expected)** are part of the default parameters in ODEON. Legacy STI parameters can also be found and activated in the Room Acoustic Parameter list (see Section 8.9). Below is a list of all STI parameters available in ODEON (single point response, multi-point response and measured impulse response).

Tip: for practical examples, you can read more in our application note on the calculation of STI in rooms or watch our video tutorial.

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STI (Legacy parameter)

The **original version of STI** uses an average gender-independent voice spectrum, and its calculation does not include any auditory effects. It is based on all the 98 combinations (14 modulation frequencies, 7 octave bands). Although this parameter is no longer part of the IEC standard, one of its advantages is that it can use relative SPLs, so it does not require a full calibration. Nevertheless, it is still important that the background noise (SPL) is set in a relative level if relative source gains are used. To exclude the background noise entirely from calculations, leave the background noise levels at -99 dB in the Room setup.

STI_{Male} and STI_{Female}

STI_Male and **STI_Female** are based on a gender-specific spectrum, and they include auditory masking, hearing threshold and octave band overlap. In particular, compression effects in the human hearing are included, meaning that STI decreases for high levels. This is especially relevant for Voice Alarm systems. The two parameters must use actual sound levels and background noise levels, so the measurements should be carefully calibrated to obtain meaningful values. In the context of ODEON simulations, both the background noise and the source powers should be properly defined to obtain meaningful values. These must be the actual levels, as opposed to relative values.

The female STI has been removed from the IEC 60268-16 standard in the 2020 version. STI_female can still be useful in cases where a female voice is used. This is generally the case in train stations for example, precisely because female voices are known to have better intelligibility.

$STI_{Expected}$

The **expected STI** is calculated on a theoretical basis, taking into account the reverberation time of the room and the background noise, but not the explicit shape of the impulse response. Instead, an exponential decay is assumed. In other words, the STI_Expected is the value of STI that would be expected in a diffuse sound field with the same reverberation time and noise level. Comparing actual STI values with the expected ones can indicate if STI has been improved by the room – the actual values should be higher than the one expected in a diffuse field.

RASTI

The **Room Acoustics STI (RASTI)** was developed in order to quickly derive an STI estimate, without calculating all 98 combinations of modulation frequencies and octave bands. This was particularly advantageous with early measurement methods, which were time consuming. The RASTI therefore uses only two octave bands, namely 500 Hz and 2 kHz. RASTI is **obsolete** since the 2011 version of the IEC standard. Nowadays, in simulations and measurements with the sweep method as in ODEON, speed is no longer an issue.

STIPA

The **STIPA** was introduced as a fast measurement method tailored for PA systems, and it proved more accurate than RASTI. For each of the seven octave bands, two specific modulation frequencies are considered. The male speech spectrum is used for STIPA. STIPA is still commonly used nowadays when studying PA or VA systems.

8.7 DL_2 – Rate of Spatial Decay

ISO 14257 parameters (ISO 14257, 2001) can be calculated as part of the Multi point response from within the Job List. In order to calculate ISO 14257 parameters in ODEON 16, a point source needs to be defined using the Point source editor in the Source-Receiver List. This point source must be assigned a Directivity pattern which contains the text OMNI in its name. This source and no other source must

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be activated in a job and a number of receivers with different distances from this source must be defined. If the above conditions are not met, these ISO parameters are not available in the Multi point response display.

Remember: The ISO 14257 parameters need certain conditions to be met in order to show up in the Multi point response display: Only one OMNI source active and a number of receivers placed at different distances.

The rate of spatial decay DL_2 is the decay of sound pressure level per doubling of distance. The DL_2 parameter is intended to characterise the acoustic performance of workrooms.

DL_2 is calculated in ODEON according to (ISO 14257, 2001). The values to be expected for the DL_2 parameter are, according to (Ondet, et al., 1995): 1 to 3 dB for reverberant rooms and 2 to 5 dB, for ideally treated rooms. The design criterion for DL_2 is set to 3.5 dB or better according to (ISO 11690-1, 1996).

The DL_2 parameter is calculated as part of the Multi Point response. If the job only contains one active source, the active source is a point source, and if more than one receiver is defined, the distance between the source and the receivers is not the same for all receivers. Please notice that one misplaced receiver may ruin the entire DL_2 calculation, thus it is a good idea to check the receiver positions - or even better - check the individual results of the Multi Point calculation.

DL_2 is stated for the frequency bands 63 Hz to 8 kHz, and $DL_{2,Co.}$ is the A-weighted Rate of Spatial Decay for the frequency bands 125 Hz to 4 kHz. For DL_2, as well as $DL_{2,Co}$ the correlation coefficients are calculated. If the correlation coefficients are low, this may indicate bad locations of source and/or receivers, however it may also indicate a very low damping in the room (the Spatial Decay Curve being almost horizontal).
The measuring points (Receivers) and the source position are of course essential to the DL_2 parameters and should follow (ISO 14257, 2001). As an example, a path of receivers may be chosen in the following distances from the source (using logarithmic increment):

1, 2, 4, 5, 6.3, 8, 10 metres

The positions should also follow the standard with respect to distance from floor and reflecting surfaces. ODEON will use all the receivers defined in the Receiver list. The Multi point response display will calculate and display values for DL_2 based on all the receivers visible in the 3D Source and Receivers tab in the Multi point response. Make sure to create a group with relevant receivers in this display – or simply deactivate irrelevant ones.

8.8 ISO 3382-3 (Open-plan offices) parameters

ISO 3382-3 parameters (ISO 3382-3, 2012) can be calculated as part of the Multi point response from within the Job List. In order to calculate ISO 3382-3 parameters in ODEON 16, a point source needs to be defined in the Point source editor. This point source must be assigned the Directivity pattern: ISO3382-3_OMNI.SO8. This source and no other source must be activated in a job and a number of receivers must defined within a distance of 2 to 16 metres from this source. If the above conditions are not meet these ISO parameters are not available in the Multi point response display.

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Remember: The ISO 3382-3 parameters need certain conditions to be met in order to show up in the Multi point response display: only one ISO382-3 OMNI source active and a number of receivers placed at distances between 2 and 16 metres from the source.

The ISO standard 3382-3 describes a range of parameters to investigate the influence of room acoustics in open plan offices. There are two application notes on our website explaining how to work with these parameters. The following parameters are supported:

Spatial distribution of *STI*

This curve shows the decrease of speech transmission index as a function of the distance from the source.

Distraction distance - r_D

It is the distance from the sound source where the speech transmission index falls below 0,50. Here **we focus on the receiver** and his/her ability to concentrate when somebody talks at a distance. Further than the distraction distance, concentration and privacy start to improve dramatically for the receiver.

Privacy distance – r_P

It is the distance from the speaker where the speech transmission index falls below 0,20. Here **we focus on the talker** and how well his/her speech is protected from being spied by the receivers in the office. Further than the privacy distance, concentration and privacy are experienced very much the same as between separate office rooms.

Remember: We want both Distraction distance and Privacy distance to be as short as possible, but for different reasons. In the first, we want to ensure that the receiver is not distracted by people talking in the office. In the second we want to ensure that the talker (source) cannot be *spied* by the receivers.

Spatial decay rate of A-weighted SPL of speech – $D_{2,S}$

This curve shows the decrease of the A-weighted SPL per doubling of distance from the sound source. The sound source emits noise with the sound power spectrum of normal speech (directivity pattern: ISO3382-3_OMNI.SO8).

A-weighted speech at 4 meters

Nominal A-weighted SPL of normal speech at a distance of 4m from the sound source. These levels are summed up over the octave bands from 125 to 8000 Hz.

A-weighted background noise

The quantity shows the level of background noise summed up over the octave bands from 125 to 8000 Hz.

8.9 Edit/Make Room Acoustic Parameters

In ODEON, the user is able to edit the room acoustic parameters calculated in the point response - or define their own. Get more information on how to do this by using the context-sensitive help (F1 shortcut) while having the Room Acoustic Parameters list open.

In the Room acoustic parameter list, you can select which room acoustic parameters will be visible in results, what range graphs will display for different parameters, change the parameters or make new ones.

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In the unexpanded view, you can see which parameters that will be visible in the results. By clicking the plus in the upper-right corner, you go to the expanded view. Here you can change visibility the parameters, edit parameter definitions and create new ones.

The more basic user options are:

- Change the name of a parameter
- Make a parameter active/inactive by using the 'visible' option.
- Set parameters such as T_{30} and Centre Time, which have a natural origin, to be displayed in graphs with ordinates starting at zero.
- Set a manual range of values in the grid-display. If not set, the range will be automatic for most parameters, and therefore changing for each calculation.
- Choose if the Jnd is in %. The default settings will be in reference to literature, so only change it if needed.
- Choose which of the parameters are measured at all.

The advanced user options are:

- Define the Type of a parameter: Reverberation, T30, SPL, Centre Time, Formula, Dietsch, MTI, MTI(corrected), G, G(early), G(late) and Lj.
- Edit the formula for a parameter. How to do this is mainly described in the help file, press F1 when in the Room acoustic parameters list.
- Make a new parameter. How to do this is mainly described in the help file, press F1 when in the Room acoustic parameters list.

You can also:

- Save a parameter list for later use.
- Load a saved parameters list.
- Restore default parameters list.

Hint! Odeon Auditorium and Combined includes a large number of predefined room acoustics parameters and allows this list to be expanded. Depending on the type of project you may want to entirely exclude and to make some parameters invisible by default. Use the Load parameters from program folder to use one of our predefined pre-sets for different kinds of projects e.g. Class room, Concert hall, Industri, Open plan office and Rock_venue. This will make the calculations results shorter and clearer and make it faster to scroll between parameter results.

The value of energy intervals in the left side of the window can be used as a variable in a parameter expression, when changing or making a new parameter. If you have to use an energy interval from a specific time point t′ to the end of the response, you have to make use of the predefined whole response length and subtract the interval from t=0 sec to t′ (e.g. E_Omni50ms_Total = E_Omni_Total - E_Omni50ms). For a formula type, the equation can be written explicitly in the white box. A list of all mathematical expressions available in the edit formula mode is found in Appendix J: Mathematical Expressions.

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9 Calculation Principles

ODEON is an energy-based room acoustic modeller, meaning that sound waves are represented by rays. A ray can be understood as a straight line connecting a source and a receiver. Reflections are represented by image and secondary sources, where the sound is still considered as rays.
These simplifications make it possible to calculate the acoustic response in large spaces, while maintaining a short computation time and a high level of accuracy. Phase information is not included in the propagation of sound.
All calculations in ODEON are performed in the energy domain - not in the pressure domain. Therefore, the acoustic differential equations cannot be solved directly as it is done in *Finite Element* (*FEM*) or *Boundary Element* (*BEM*) methods.

9.1 What can be modelled in ODEON

The calculation methods from room acoustics that are used in ODEON are mostly for geometrical tasks, and they are valid for spaces and frequencies where high modal overlap occurs. That is, when there are so many modes (standing waves) that the sound field becomes smooth. Single modes are prominent at low frequencies, in small, reverberant rooms. But fortunately, a moderate-sized space (like a classroom) is already considered a big volume where there is high modal overlap, so the room acoustic algorithms used in ODEON can be applied safely. The following theoretical formula, proposed by Schroeder, gives the minimum frequency at which there is guaranteed to be enough modal overlap that such energy-based methods can be applied:

$$f_{sch} = 2000\sqrt{\frac{RT}{V}}$$

RT is the reverberation time in the room (inversely proportional to absorption) and V is the volume. As an example, in a concert hall with reverberation time 2 sec and volume 600 m^3, the Schroeder's frequency would be 115 Hz. Therefore, an energy-based calculation in the octave band 125 Hz can be considered reliable in terms of modal overlap, since most of the frequencies in the band are already above the Schroeder frequency. Additionally, in practice, we can accept frequencies well below the Schroeder's limit, especially in large halls. Experience has shown that even frequencies lower than 50% from this limit can be reliable.
Taking into account the limitations from the energy-based (high frequency) methods, we assume that ODEON calculations are more reliable in moderately-sized and larger rooms. As absorption becomes higher, this size can be reduced. ODEON has been successfully used for rooms such as:

- Meeting Rooms.
- Classrooms.
- Offices – open plan offices.
- Auditoriums.
- Concert halls.
- Opera halls.
- Big rehearsal halls.
- Small scale city plans (outdoor modelling).
- Cathedrals, worship spaces.
- Restaurants.
- Shopping malls.
- Multi-floor buildings with atriums.
- Cinemas.
- Theatres.
- Open theatres.
- Train stations.
- Airport terminals.
- Noise halls (factories).
- Industrial spaces.

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9.2 Global decay

ODEON contains two methods for calculating the global decay of rooms. These should not be used in place of calculations from sources to receivers, but are good for first or global impressions:

- Quick Estimate, which is available from the Materials List, is the fastest method allowing quick evaluation of the effect of modifying materials. This method should be considered only as a tool for preliminary results.
- Global Estimate is a more precise method, allowing high quality results, though still not representing the sound experience of a receiver at a specific position, which may be slightly different.

Quick Estimate

The Quick estimate tool estimates volume and total absorption, which is inserted in the Sabine, Eyring and Arau-Puchades formulas to give an estimate of the reverberation time. Instead of simply taking the areas of the surfaces and multiplying by the corresponding absorption coefficients to obtain the total absorption in the room, ODEON also sends out 'particles' from the source - assuming diffuse conditions and reflecting them in random directions, keeping track on how many times they hit each surface. Surfaces that are hit very often contain higher influence of the overall absorption coefficient of the room. Surfaces, which are not detected at all in the ray-tracing process, are left out of all calculations - and surfaces which are hit on both sides are included twice in the calculation. As a result, the estimated reverberation time corresponds to the sub-volume in which the selected source is located. Do note that if a part of the area of a surface, which is present in the sub-volume, is located outside that sub-volume (e.g. if two sub-volumes share the same floor surface) then the area and surface estimates for the statistical calculations may not be entirely correct. To partly compensate for that it is possible to set a volume manually.

The classical mean absorption coefficient is given by:

$$\overline{\alpha} = \frac{\sum_i S_i \alpha_i}{\sum_i S_i}$$

S_i and α_i are the area and absorption coefficient of the i^{th} room surface, respectively.

The modified mean absorption coefficient as experienced by the particles is:

$$\overline{\alpha}' = \frac{\sum_i H_i \alpha_i}{\sum_i H_i}$$

H_i is the number of hits on the i^{th} room surface.

In ODEON, both mean absorption coefficients are inserted in the Sabine and Eyring formulae to calculate reverberation times; the classical values are labelled Sabine and Eyring, and the values using the modified mean absorption coefficient are labelled Modified Sabine and Modified Eyring. The mean absorption coefficients used for the Arau-Puchades formula are derived in similar ways except that separate values for surface hits, area, and the corresponding mean absorption coefficients, are calculated as projections onto each of the axes of the room. The Sabine, Eyring and Arau-Puchades formulae require a value for the room volume. This is estimated by ODEON from the mean free path, experienced by ray tracing and using the well-known relation for the mean free path in a 3-dimensional room:

$$l = \frac{4V}{S}$$

where V is the room volume and S is the total active surface area. The ray-tracing process is carried out in order to estimate the room volume, considering scattering coefficients of 1 for all surfaces, rather than using the coefficients assigned to the surface in the materials list, where the mean free path formula is based on diffuse field assumptions.

The value of S is used in the sum of the areas of non-transparent surfaces, taking into account whether one, two or indeed none of the sides of a surface are visible inside the room.

Convergence criterion

A certain number of particles must be sent out and followed around the room for a stable estimate to be obtained. More and more particles are sent out in random directions until the value of the reverberation time has remained within 1% for at least 50 particles. At the end of a run, the data on how many times each surface was hit is stored. Then, if new materials are assigned to the surfaces, the reverberation time can be recalculated instantaneously, without repeating the particle tracing.

Global Estimate

The global estimate tool calculates the global reverberation times T_{20} and T_{30} using the method proposed by Schroeder (Schroeder, 1970), as well as the mean free path, and generates estimates of decay curves. Particles are sent out in random directions from the source (see Chapter 9.8) and reflected using the 'Vector based scattering method' (see Chapter 7.5). ODEON records the loss of energy in each particle, as a function of time, due to absorption in room surfaces and in the air. Summing over many particles, a global energy decay function for the room is obtained. The decay curve is corrected for energy, which is lost due to the truncation of the decay curve. This is analogous to an ordinary decay curve, except there is no specific receiver. The summation process may be carried on for as many rays as desired.

Evaluating results

When the decay curve seems smooth, you can derive the results. It is often the case that T_{30} values are larger than T_{20} values. If T_{30} values are lower than T_{20}, it is likely that the used numbers of rays were too small - in this case you can press the Recalculate button. If the reverberation times are shown as *.**, the Impulse response length defined at the Room setup page is too short to derive the reverberation parameter.

9.3 Response from Sources to Receivers

This section describes the room acoustic simulation methods used to predict the (impulse) response from sources to receivers within from the JobList. The results can be shown as Single Point Responses, Multi Point Responses and Grid Responses. In ODEON Auditorium and Combined, the predicted response can be used for auralisation of any sound clip (see Chapter 7). These simulation methods aim to mimic real impulse response measurements, although they all operate in *energy* domain, while real measurements operate in *pressure* domain (see sec. 9.1). As a result, impulse responses in ODEON are inherently positive as a function of time, corresponding to the *squared impulse response* of a real sound pressure measurement. Real measurements show both positive and negative values, like plane waves do.

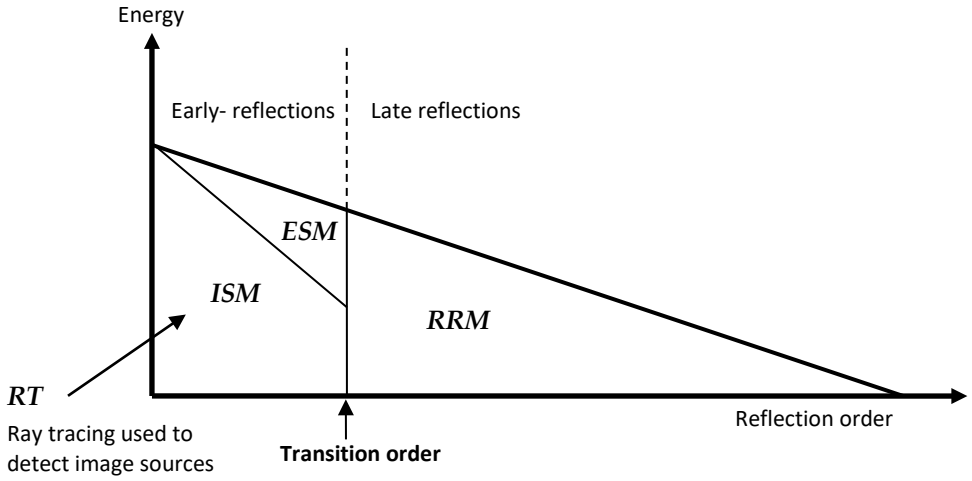
In ODEON, different simulation methods are used in combination to ensure optimal performance and precision. These are the *Image Source Method (ISM)*, *Early-Scattering Method (ESM)*, *Ray-Tracing (RT)* and *Ray-Radiosity Method (RRM)*. The first three methods collaborate in the **early-reflections**

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part, while the last one is essentially the **late-reflections part**. In point source calculations both the 'early' and 'late' reflection parts are used. In line or surface source calculations, only the 'late' reflection part is used.

Transition order

Every reflection is classified by an order, according to how many walls have been involved in the reflection path. In ODEON, a transition order is used to determine where the **early-reflections part** stops and the **late-reflections part** begins. The default value is 2, which means that all reflections that involve 2 walls are calculated according to the early-reflections part. Reflections of order higher than 2 (more than 2 walls involved) are calculated according to the late-reflections part.



Note: All the three methods may overlap in time, since the transition order can affect reflections at different times. The transition order criterion ensures that energy conservation is maintained during the gradual shifting from one method to the other.

User inputs

Various parameters controlling the calculation methods are accessible by the user in the Room setup. The Number of late rays and Transition order are of special importance, and should always be evaluated by the user (see Chapter 10).

Early-reflections part

During the early-reflections part the *Image Source Method (ISM)* and *Early-Scattering Method (ESM)* are used to determine the reflections and scattering originated from point sources up to the transition order. These two methods provide high deterministic accuracy in tracking the early reflections, which are probably the most important in the whole impulse response. The early reflections towards the receiver provide significant information about the origin of sound and the distance from the source.

Image Source Method

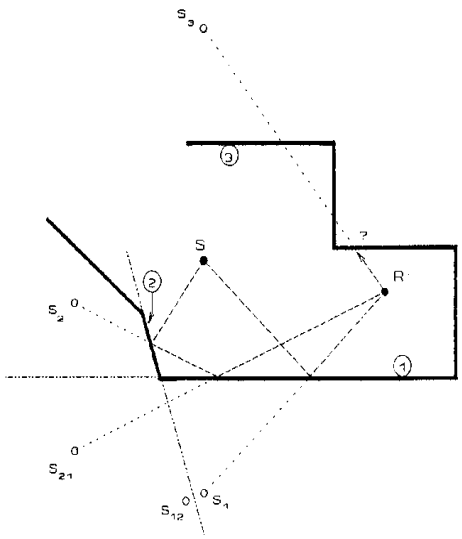
An image source is a mirroring of the source behind a wall. In the classical implementation, Image Sources are found by just taking all combinations of walls up to a given reflection order, e.g. Source-$Wall_1$-$Wall_2$, $Wall_1$-$Wall_3$ and so on. After that, a visibility check has to be performed to determine which image source is actually visible from the receiver. If not, the image source is discarded. For simple rooms with few surfaces construction and visibility check can be easily accomplished. However, for rooms with thousands of surfaces, developing the whole tree of combinations can

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lead to a huge number of image sources, with a significant percentage being not visible – therefore being discarded afterwards.

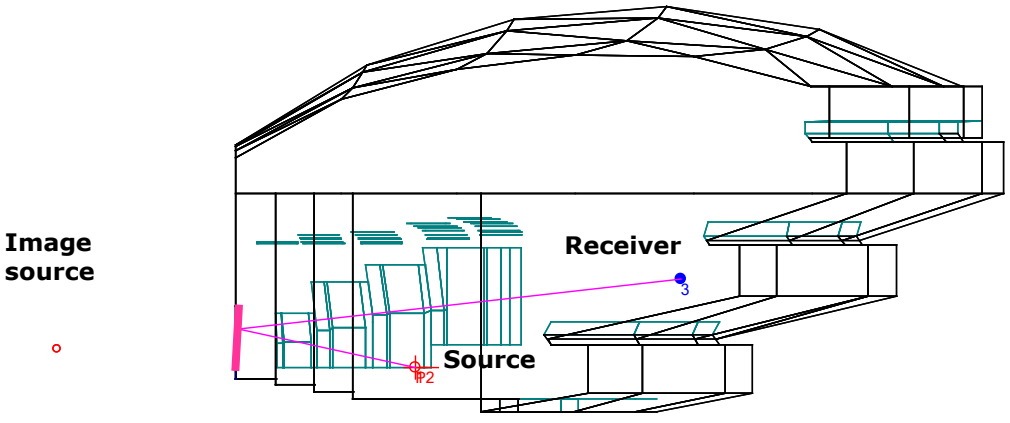
In ODEON, a more efficient approach is utilized. A fast ray tracing algorithm is initiated from the source in order to help 'detecting' only visible image sources. Therefore, only the actual amount of valid image source is generated. The algorithm works as it follows:

- A number of early rays is generated from the source (ODEON suggests a number based on room dimensions, Transition order and surface sizes).
- The rays are reflected *specularly* until they reach the Transition order.
- For each reflecting surface, a new image source is added to an image source tree. The number of image sources stored after this process is usually much lower than all combinations of reflecting surfaces, but the images are all valid because hidden surfaces and most very small surfaces are excluded. The calculation so far is receiver-independent.
- For each of the image sources, ODEON performs a visibility check by following the corresponding reflection path back to the source. If this path is unobstructed until the source, then the image source is found visible, and a reflection is added to the impulse response. However, the reflection path may be blocked by other surfaces, or it may not hit the right surfaces, for instance if they are too small. In such cases, the image is hidden and does not contribute to the impulse response. The figure above illustrates the concept of visible and hidden image sources.



Visible and invisible images. Images S1 and S21 are visible from R, while S2, S3 and S12 are not.

Specifically, we focus on three first-order image sources S_1, S_2 and S_3, generated from source S, behind walls 1, 2 and 3, respectively. More image sources can be generated behind the other walls, but we only focus on these three at the moment. The image sources S_1, and S_2 generate further second-order image sources S_{12} and S_{21} behind the extension of walls 2 and 1, respectively. The line connecting S_2 and receiver R does not pass through the corresponding wall 2, therefore that reflection cannot exist. In this case S_2 is not visible from the receiver. The same happens with S_3 and S_{12}. They are not visible from the receiver through walls 3 and 2, respectively. At the end, only sources S_1 and S_{21} are visible and are counted in the impulse response.

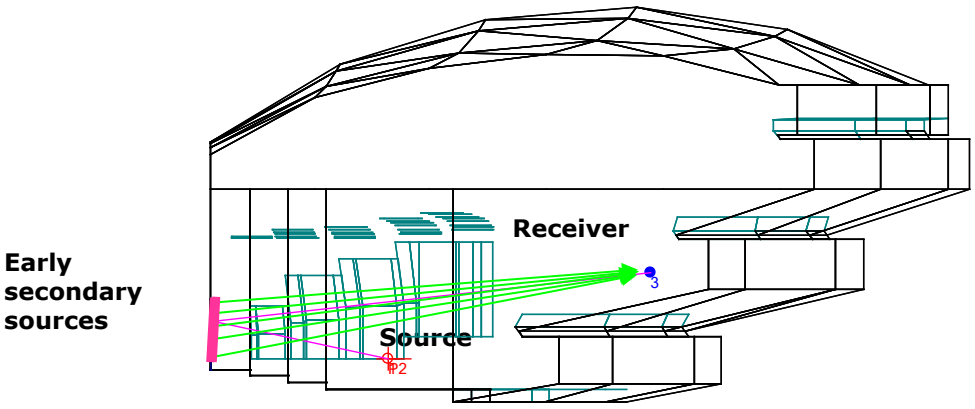


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Early Scattering Method

For each visible image source that is generated, a range of *early secondary sources* is generated on the surface the image source corresponds to. These account for scattering in the following way:

- These *early secondary sources* will emit early scatter rays from the image source's surface as defined by the Number of early scatter rays parameter. The early scatter rays will be traced from the current reflection order and up to the Transition order. At each reflection point of the early scattering rays, including the point of origin, a new *early secondary source* is created.
- Every *early secondary source* visible from the receiver adds a reflection to the impulse response.



The attenuation of an image or early secondary source is calculated taking the following into account:

- Directivity factor of the primary source in the relevant direction of radiation.
- Absorption coefficients of the surfaces involved in generating the image (can be angle dependent if Angular absorption is enabled in the Room setup).
- Air absorption due to the length of the reflection path. The calculation is based on ISO 9613 (ISO 9613-1, 1993) and takes into account only the centre frequency of each octave band.
- Scattering loss (frequency dependent), due to the scattered energy which is handled by a 'scattering tree'. Based on the scattering of the surface, the sound energy is distributed between image sources (specular contribution) and *early secondary sources* (Lambert sources) from the same surface. If new image sources are again generated based on the current image source (if the Transition order has not been reached yet), the distribution will follow a scattering tree because of energy conservation principles. This allows a realistic calculation of early scattering. For more information about scattering, read section 9.5.

Example

In short, each time ODEON detects an image source, an inner loop of (scatter) rays (not visualised in the 3D Investigate Rays display) is started, taking care of the scattered sound which is reflected from this image source/surface.

If all scattering coefficients in a room are 0.5, then the specular energy of a first order image source is multiplied by (1-0.5) - and the specular energy of a second order image source is multiplied by (1-0.5)*(1-0.5). The scattering rays handle the rest of the energy.

Late-reflections part

The Late-reflections part uses an ODEON-modified Ray-tracing method, called *Ray-radiosity method*, which proves to be very efficient and receiver-interdepended. In the classical implementation of Ray-tracing, rays are thrown from the source, get reflected and traced by the algorithm. A detection sphere is formed around the receiver, so that whenever a ray intersects the

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sphere, the corresponding the reflection is added at the impulse response. Two main disadvantages of this method are that:

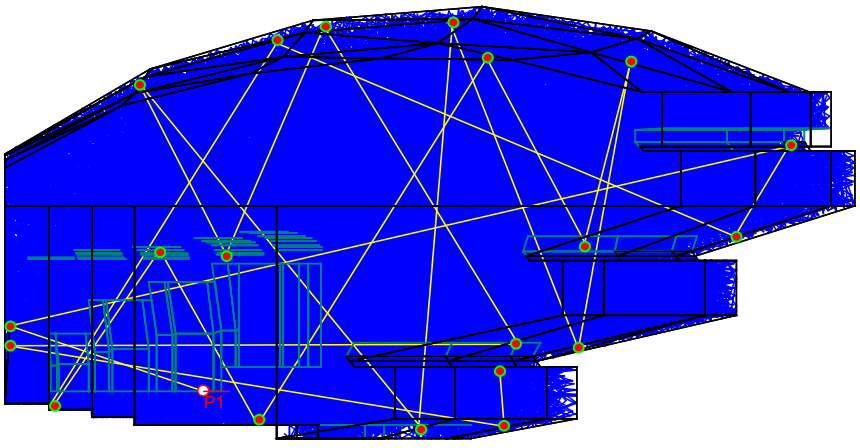
- the size of the detection sphere is quite arbitrary - despite of the various methods used to specify it.
- the ray tracing needs to be re-run for every new receiver.

The *Ray-radiosity method* removes these disadvantages by dividing the process in two parts, the *Rendering* and *Gathering*. The rendering part of the calculation only stores geometrical information which does not involve material data nor receiver position. For the gathering part, the sources are "collected" by the receiver adding information to the reflectogram.

Rendering (receiver-independent part)

The purpose of this process is to find virtual sources that radiate energy into the room. Rather than thinking of reflections, the idea is to substitute the room with a number of sources at various positions in space, each of the sources given the appropriate delay.
The process is divided into an early part (for point sources only) and a late part (for all source types).

- A number of late rays specified in the Room setup are emitted from the source.
- These will hit the surfaces of the room, be reflected, hit new surfaces, be reflected again, and so on until reaching the Max. Reflection order as specified in the Room setup. They will be reflected according to the vector based scattering method (described later) and taking into account the scattering due to the surface size and surface roughness.
- Each time a ray gets reflected; its reflection order is increased by one. The first orders of reflections have been included already during the *Early-reflections part*; therefore, no action is taken for the ray up to the Transition order set in the Room setup.
- Once the reflection order is higher than the Transition order, the ray will start generating one *late secondary source* every time it hits a surface. This process creates a map of late secondary sources all over the room and we call it *rendering*.
- The *late secondary sources* may have a Lambert, Lambert Oblique or Uniform directivities, depending on the calculation settings.



Each time a 'late' ray hits a surface, a *late secondary source* is generated. The process is repeated for all the late rays set in the Room Setup.

The late reflection process does not produce an exponential growing number of reflections (with respect to time), as the image source method would suggest. Instead, it keeps the same

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reflection density during the whole calculation, allowing for reasonable calculation times. The attenuation of a secondary source is calculated taking the following into account:

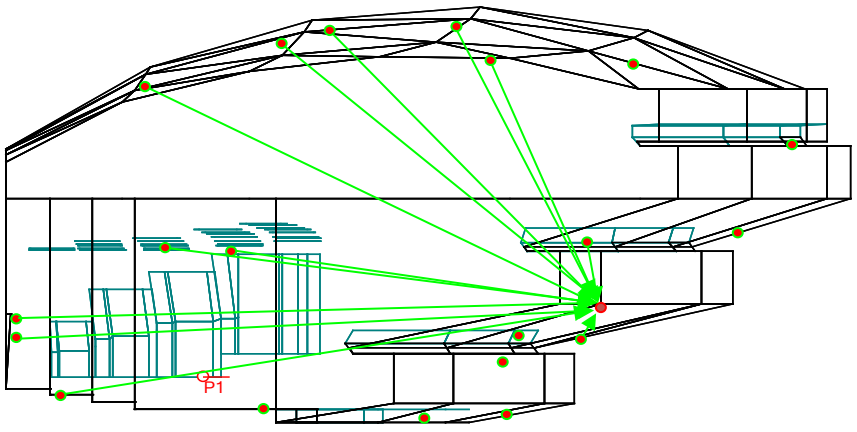
- Directivity factor of the primary source in the relevant direction of radiation (used with point sources only).
- Absorption coefficients of the surfaces involved in generating the image (can be angle dependent if Angular absorption is enabled in the Room setup).
- Air absorption due to the length of the reflection path. Calculation based on ISO 9613 (ISO 9613-1, 1993).
- Directivity factor for secondary sources e.g. the Lambert, Oblique Lambert or Uniform directivity, see later.

Remember: The rendering (receiver-independent part) stores a large file containing the ray history. These files will speed up calculations of other receivers, making use of the same late secondary sources. However, if these files are not erased when finishing a project, you may gradually fill up your hard drive. Use File>Delete files>Delete calculation files to save space from such history files, which can be easily recalculated.

When all calculations in a room have been carried out, use the File>Tidy directory tool to free some more disk space. The Tidy directory tool will clean a complete directory and its sub-directories and delete all calculation files for all rooms (A directory in this context can also be the C:\ drive in which case it will be a lengthy process).

Gathering (receiver-dependent part)

In this part, the information from all generated *late secondary sources* is collected (gathered) to a desired receiver location. ODEON checks each secondary source to determine whether it is visible from the receiver. If it is visible, the contribution is added to the impulse response.
At this point the contributions of direct and reflected sound are collected at the receiving point allowing the calculation of the results known as Single Point, Multi Point, Grid Response and 3DMatrix.
When more than one receiver is involved, the receiver-dependent part of the process is simply repeated for each receiver. When more than one source is involved, the response at a given receiver is simply the superposition of the responses from the individual sources, each one delayed appropriately, if a delay is applied to the source.



After the ray tracing process is completed, the receiver will 'collect' the contribution to the impulse response from the secondary sources.

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Remember: ODEON automatically takes care of handling which of the calculations and result files are currently consistent with user-entered data, erasing those that are no longer valid. Thus, in some situations you may experience that ray tracing calculations have already been done and are still valid, in other cases they have to be recalculated.

One of the advantages of the late ray tracing method (ray radiosity) used in ODEON compared to more traditional methods is that rays do not even have to come near to the receiver to make a contribution - and a late ray, being reflected 100 times, has a potential of generating 100 secondary sources. Thus, even in coupled rooms, with only a modest number of rays, it is possible to obtain a reasonable number of reflections at a receiver (which is required to obtain a result that is statistically reliable). This gives a fine balance between high reliability of the calculation results and short calculation time.

A complete histogram, containing both early and late energy contributions, is generated and used to derive Early Decay Time and Reverberation Time. The other room acoustical parameters are calculated on basis of energy collected in time and angular intervals.
For surface sources and line sources, a number of secondary sources are placed randomly on the surface (or line) of the source, each emitting one ray, and radiating a possible contribution to the receiver. The rays emitted from these source types generate an independent secondary source each time they are reflected. Compared to the calculation principle applied to the point sources, you might say that Transition order is always zero, and that only late energy contributions are collected for these source types, or rather that calculations are based exclusively on ray-radiosity. For point sources, only the late reflections are handled like surface sources and line sources. For the first couple of reflections, a method including image sources is used.

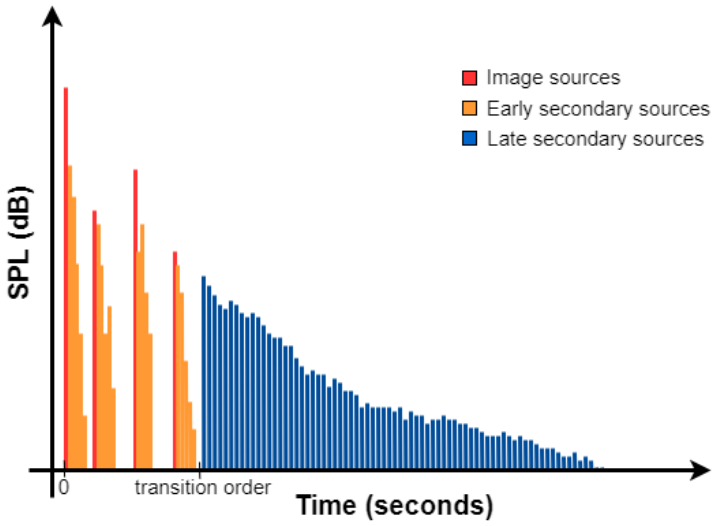
Summarizing the calculation method used for point response calculations in ODEON

We can summarize the descriptions above in the following steps. The early-reflection part is described by steps 1 to 7, while the late-reflection part by steps 8 to 11:

1. The early ray tracing is initiated from the source. Rays are reflected specularly.
2. Each time the ray collides with a surface, a new image source is added to the image source tree. Since the image source results from an existing reflection, it is valid at the same time.
3. Soon all valid image sources have been generated behind each wall, up to the specified transition order.
4. ODEON checks each image source to determine whether it is visible from the receiver.
5. If the image source is visible, then a reflection is added to the reflectogram and a range of *early secondary sources* are generated on the surface the image source corresponds to.
6. ODEON simulates a surface source, which emits the number of early scatter rays up to the Transition order.
7. Each ray that reaches the receiver without colliding with any obstacle, adds a reflection to the reflectogram.
8. The late rays are emitted from the source and are reflected around the room, taking the scattering of the surfaces into account. The rays start to be traced from the very first orders of reflection, but no action is taken up to the Transition Order, since it has been taken into account in the Early-reflections part already. The late rays are reflected until the Max. Reflection order.
9. *Late secondary sources* are generated at each reflection point (when a ray hits a surface).
10. The ray path is traced from the *late secondary sources* directly to the receiver.
11. ODEON checks each l*ate secondary source* to determine whether it is visible from the receiver. If visible, the contribution is added to the reflectogram.

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The following figure illustrates the process of adding reflections during the early and the late part.



A representation of the contributions added to the reflectogram.

The reflections generated by the image sources and early secondary sources, during the early reflection method, occur before the Transition order. Generally, the reflections from early secondary sources are reinforcing the reflection from the image source related to the same surface. After the transition order, reflections are generated by the late secondary sources using the late reflection method. In reality, all three methods will overlap in time as the transition criterion is the transition order which is not strictly linked to time. This creates a smooth transition between the methods creating no sudden jumps in the decay of sound.

9.4 Angle-dependent absorption

In reality sound absorption of materials depends on the angle of incidence. However, information on angle dependent absorption is difficult to measure and rarely available. Therefore, ODEON has implemented algorithms which derives angle dependent absorption from the random incidence absorption coefficients which are commonly available – in the Odeon material library, from manufacturers of acoustics materials etc.

Absorption is angle dependent, but will work differently between “soft” and “hard” materials. Hard concrete would be an example of a hard material, and a porous absorber would be an example of a soft material. ODEON determines if the material can be seen as a soft material, hard material or something in between from the absorption coefficients.

The average absorption coefficient for the 1k, 2k and 4k Hz octave bands gives a value that is used as follows:

- If the average value is exactly 0.3, the random incidence absorption coefficient for the material (as set in the material list) will be valid for all angles of incidence.
- If the average value is exactly 0, the material is seen as a hard material and the absorption will be affected by the angle of incidence as explained further below.
- If the average value is exactly 1, the material is seen as a soft material and the absorption will be affected by the angle of incidence as explained further below.
- If the average is between 0 and 0.3, the material is something in between hard and not. The absorption will be a mix of the random incidence absorption coefficient (as given in the material list) and the angle absorption for hard materials. A material can be more or less hard, and therefore the mix is based on linear interpolation from where it is placed between 0 and 0.3.

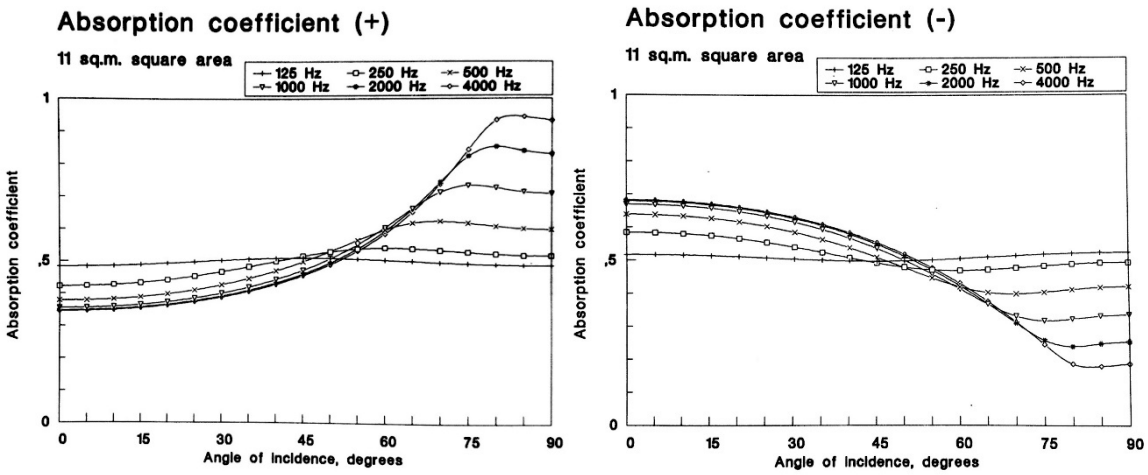
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- If the average is between 1 and 0.3, the material is something in between soft and not, and the absorption will be a mix of the random instance absorption coefficient (as given in the material list) and the angle absorption for soft materials. A material can be more or less soft, and therefore the mix is based on linear interpolation from where it is placed between 1 and 0.3.

The absorption for hard and soft materials will change based on the angle of incidence of the sound. On one end we a have perpendicular, direct incidence, which is said to have an angle of incidence of 0 degrees. On the other end we have a parallel, grazing, incidence which corresponding to an angle of incidence of 90 degrees. And then we have that:

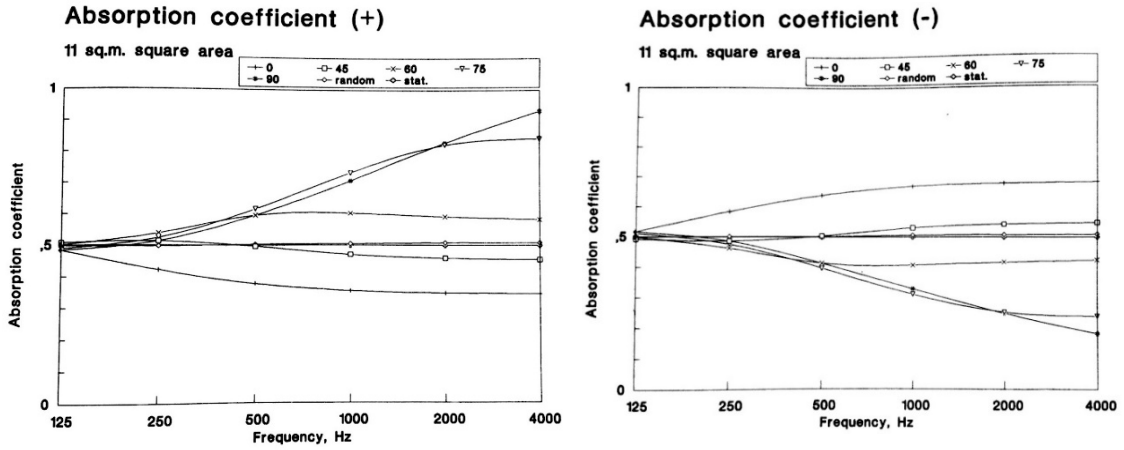
- Hard materials: the absorption will be higher the larger the angle of incidence (that is, the closer the angle is to 90 degrees). And the angle will affect the higher frequencies the most. See graphs below.
- Soft materials: it will be the opposite from hard materials. The absorption will be higher for smaller angle of incidence, but the angle will still affect the higher frequencies the most.

The statistical information can be seen in the graphs below from (Rindel 1993).



Hard material (high impedance). Soft material (low impedance).

Calculated absorption coefficient as a function of angle of incidence and with the frequency as the parameter. A statistical absorption coefficient of 0.5 and a square area of 11 m^2 has been assumed. (Rindel 1993).



Hard material (high impedance). Soft material (low impedance).

Calculated absorption coefficient as a function of frequency and with the angle of incidence as the parameter. A statistical absorption coefficient of 0.5 and a square area of 11 m2 has been assumed. (Rindel 1993).

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9.5 Scattering

This chapter covers the calculation methods used for scattering. For a guide on how to choose a correct scattering coefficient for a project/material, please look in the Materials chapter (chapter 4) of this manual.

Scattering in ODEON uses multiple different methods to get the best results. This, however, can make it a bit difficult to fully understand as a user, but for most users it is not necessary to understand the details in order to use scattering.

The acoustical calculations in ODEON are divided into two parts: early and late. Scattering is dealt with two different ways in the two parts. Besides this, scattering is both surface size dependent and frequency dependent, and ODEON takes this into account.
A total scattering coefficient is applied to each surface based on both the user chosen coefficients and, if active, calculations of extra scattering from the size of the surface and distance to the source.

Scattering is part of three different calculations. Very briefly, the following can be stated (explained in more detail further below):

- **The reflections of the rays used in 'late' rays** will be based on the scattering coefficients. This scattering is not influenced by frequency.
- **The *late secondary sources* (Oblique Lambert Sources) made by 'late' reflections** will be based on the scattering coefficients, angle of incidence, and frequency of the octave band.
- **The 'early' reflections will make normal Lambert Sources and Image Sources**, and the distribution of sound energy between them will be based on the scattering coefficients.

How scattering generally works for the late reflections:

- A chosen number of so-called 'late rays' is emitted from the sound source. When a ray hits a surface, it will get a reflected direction. The calculation of the reflected direction is based on the user-chosen scattering for the surface and if Reflection based scattering is enabled; on the angle of incidence, the size of the surface and distance from the source. For every point where a ray hits a surface, a *late secondary source* is generated.
- If a *late secondary source* is visible to a receiver, it will have influence on the decay curve and the acoustical results. The amount of sound power is based on the absorption coefficients the ray has met, but also (if active) on the Oblique Lambert method. The Oblique Lambert is based on the scattering coefficient of the surface, the angle of incidence, and frequency of the octave band.

How scattering generally works for the early reflections (explained in detail further below):

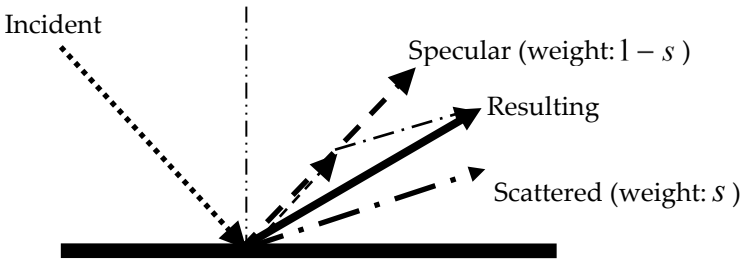
- For the early reflections, up to the set transition order, another method involving mirror sources is used.
- Beside an image source, there will be made a number of *early secondary sources* on each of the surfaces involved in the early reflection paths. The 0. order *early secondary sources* will follow Lambert directivity. For higher reflection orders up to the transition order Oblique Lambert is applied, in any the directivity will be different for each octave band, according to the scattering coefficients.
- The sound power will be distributed between the image sources and the *early secondary sources* according to the chosen scattering for the surface. If 100% scattering, only the *early secondary sources* will be active, if 0% scattering only the image source.

Vector Based Scattering – reflecting a 'Late ray'

Vector based scattering is an efficient way to include scattering in a ray-tracing algorithm. The direction of a reflected ray is calculated by adding the specular vector according to the laws of

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reflection, scaled by a factor $(1-s)$ to a scattered vector with random direction (where s is the scattering coefficient), following the angular Lambert distribution of ideal scattered reflections: $\mathrm{Sin}(2\varphi)$ (Rindel, 1995) which has been scaled by a factor s. If s is zero, the ray is reflected in the specular direction, and if s equals 1, the ray is reflected in a completely random direction. Often the resulting scattering coefficient may be in the range of say 5 to 20 percent, and in this case, rays will be reflected in directions which differ just slightly from the specular one, but this is enough to avoid artefacts due to simple geometrical reflection pattern.



Vector based scattering. Reflecting a ray from a surface with a scattering coefficient of 50% results in a reflected direction which is the geometrical average of the specular direction and a random (scattered) direction. Note: Scattering is a 3D phenomenon, but here it is shown in 2D for simplicity.

The Reflection Based Scattering coefficient

When the reflection based scattering coefficient is activated in the Room setup, ODEON will do its best in estimating the scattering introduced due to diffraction. The user defined scattering coefficients assigned to the surfaces should only include scattering occurring due to surface roughness, then diffraction phenomena are handled by ODEON. In many cases a scattering coefficient of, say 5%, for all smooth surfaces may be sufficient. The Reflection Based Scattering Method combines scattering caused by diffraction (due to typical surface dimensions, angle of incidence, incident path length and edge diffraction) with surface scattering. Each of the two scattering effects is modelled as frequency dependent functions. The benefits are two-fold:

- Separating the user defined surface scattering coefficient from the scattering that results room geometry, makes it easier for the user to make good estimates of the coefficients.
- Scattering due to diffraction is distance and angle dependent, and as such it is not known before the source and receiver are defined and the actual 'ray-tracing' or image source detection takes place. One example could be a desktop providing a strong specular component to its user, whereas it will provide scattered sound at remote distances.

The method has several advantages. For starters, it makes life easier for the user because the same scattering coefficient can be used for different surfaces, no matter their size. It also allows a better estimate of the actual scattering occurring at a reflection point, because scattering caused by diffraction is not fully known before the actual reflections are calculated, thus angles of incidence, path-lengths, etc., are known. In order to allow these features to be included in predictions, the Reflection Based Scattering Coefficient s_r is calculated individually for each reflection as calculations take place, by combining the surface roughness scattering coefficient s_s with the scattering coefficient due to diffraction s_d:

$$s_r = 1-(1-s_d)\cdot(1-s_s)$$

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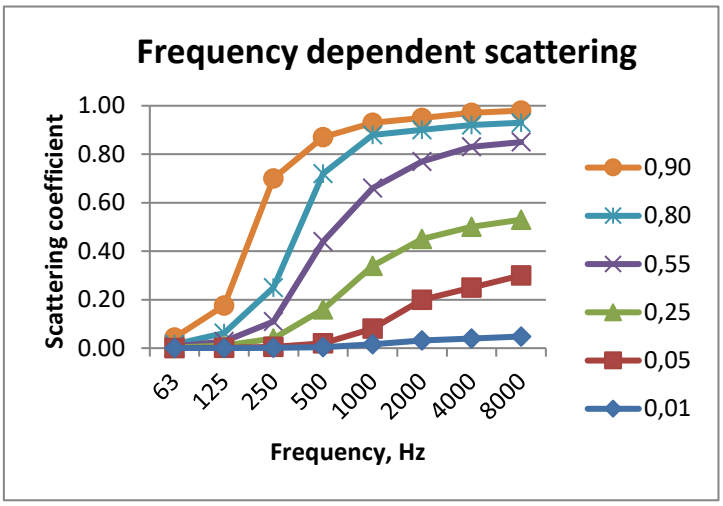
S_s -Surface scattering

Assigning materials to the surfaces, the scattering coefficient can be defined by the user in the surface list. This is the scattering coefficient at mid frequencies (logarithmic average of 500 and 1000 Hz).

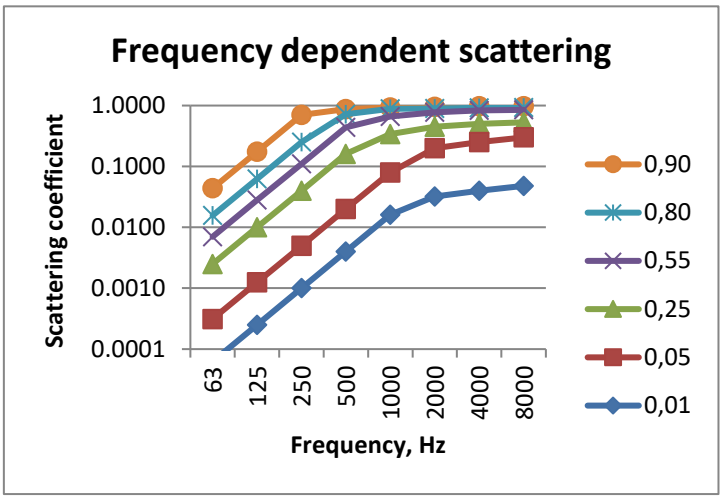
However, for the calculations, ODEON uses scattering coefficients that vary with the frequency. The actual scattering coefficients used in each octave 7band are shown in the figures. Interpolation between the curves is applied for other values.

Of the two figures, one is shown with a linear y-axis and the other with a logarithmic y-axis. Scattering coefficients are best displayed with a logarithmic axis. The scattering coefficient decreases towards low frequencies, and theoretically the slope is a factor of 4 per octave. This is clearly shown as straight lines in the display with logarithmic axis.

Very small scattering coefficients can be applied for very smooth surfaces, but the scattering coefficient can never be 0.



The scattering of a material changes due to frequency. The user chooses the scattering for the mid frequency (707Hz). This value determines a curve, which is extrapolated towards high and low frequencies, and is used for the frequency dependent calculations in ODEON.



Same as above, but with a logarithmic y-axis. When changing scattering coefficient, a doubling is comparable in a logarithmic axis. For example, a change from 0.05 to 0.1 is comparable to a change from 0.1 to 0.2.

Remember: The scattering coefficients influence the simulations, and the effect of changing the scattering coefficient depends on the relative change. For example, a change from 0.05 to 0.1 is comparable to a change from 0.1 to 0.2. Scattering coefficients higher than 0.5 means in practice a strong scattering, and a further increase will change very little.

S_d -Scattering due to diffraction

In order to estimate scattering due to diffraction, reflector theory is applied. The main theory is presented in (Rindel, 1986; Rindel, 1992). The goal in these papers was to estimate the specular contribution of a reflector with a limited area; given the basic dimensions of the surface, angle of incidence, incident and reflected path-lengths. Given the fraction of the energy which is reflected specularly we can however also describe the fraction s_d which has been scattered due to diffraction. A short summary of the method is as follows: For a panel with the dimensions $l \times w$: above the upper limiting frequency f_w (defined by the short dimension of the panel) the frequency response can be simplified to be flat, i.e. that of an infinitely large panel. Below f_w the response

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will fall off with by 3 dB per octave. Below the second limiting frequency f_l, a decay of 3 dB per octave is added, resulting in a decrease of 6 dB per octave. In the special case of a quadratic surface, there will only be one limiting frequency below which the specular component will decrease of 6 dB per octave. The attenuation factors K_l and K_w are estimates to the fraction of energy which is reflected specularly. These factors take into accout the incident and reflected path lengths (for ray-tracing we have to assume that reflected equals incident path length), angle of incidence, and distance of reflection point to the closest edge of the surface.

$$K_w = \begin{cases} 1 & for \quad f > f_w \\ \dfrac{f}{f_w} & for \quad f <= f_w \end{cases} \qquad K_l = \begin{cases} 1 & for \quad f > f_l \\ \dfrac{f}{f_l} & for \quad f <= f_l \end{cases}$$

$$f_w = \frac{c \cdot a^*}{2(w \cdot \cos\theta)^2} \quad , \qquad f_l = \frac{c \cdot a^*}{2 \cdot l^2}$$

Where:

$$a^* = \frac{d_{inc} \cdot d_{refl}}{2(d_{inc} + d_{refl})}$$

If we assume energy conservation, then we must also assume that the energy which is not reflected specularly has been diffracted - scattered due to diffraction. This leads to the following formulae for our scattering coefficient due to diffraction:

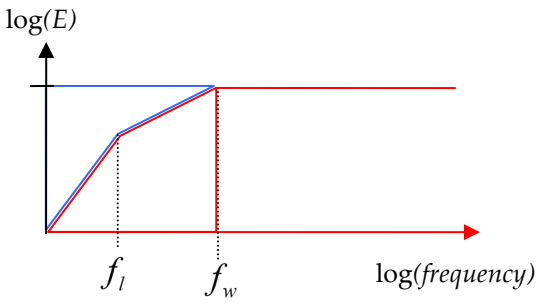
$$s_d = 1 - K_w K_l \times (1 - s_e)$$

In order to compensate for the extra diffraction which occurs when a reflection appears close to an edge of a free surface, the specular component is reduced by a factor $(1 - s_e)$. The edge scattering coefficient is defined to be 0.5 if the reflection occurs at the edge of a surface saying that half of the energy is scattered by the edge and the other half is reflected from the surface area. If the reflection point is far from the edge, the edge scattering becomes zero – initial investigations suggests that edge scattering can be assumed to zero when the distance to the edge is greater than approximately one wave length, therefore we define the edge scattering coefficient as:

$$s_e = \begin{cases} 0 & for \quad d_{edge} \times \cos\theta \geq \dfrac{c}{f} \\ 0.5\left(1 - \dfrac{d_{edge} \times \cos\theta \times f}{c}\right) & for \quad d_{edge} \times \cos\theta < \dfrac{c}{f} \end{cases}$$

As can be seen, scattering caused by diffraction is a function of a number of parameters, of which some are not known before the actual calculation takes place. An example is that oblique angles of incidence lead to increased scattering, whereas parallel walls lead to low scattering, and sometimes flutter echoes. Another example is indicated by the characteristic distance a^*, if source or receiver is close to a surface, this surface may provide a specular reflection even if it is small, on the other hand if far away it will only provide scattered sound, $s_d \approx 1$.

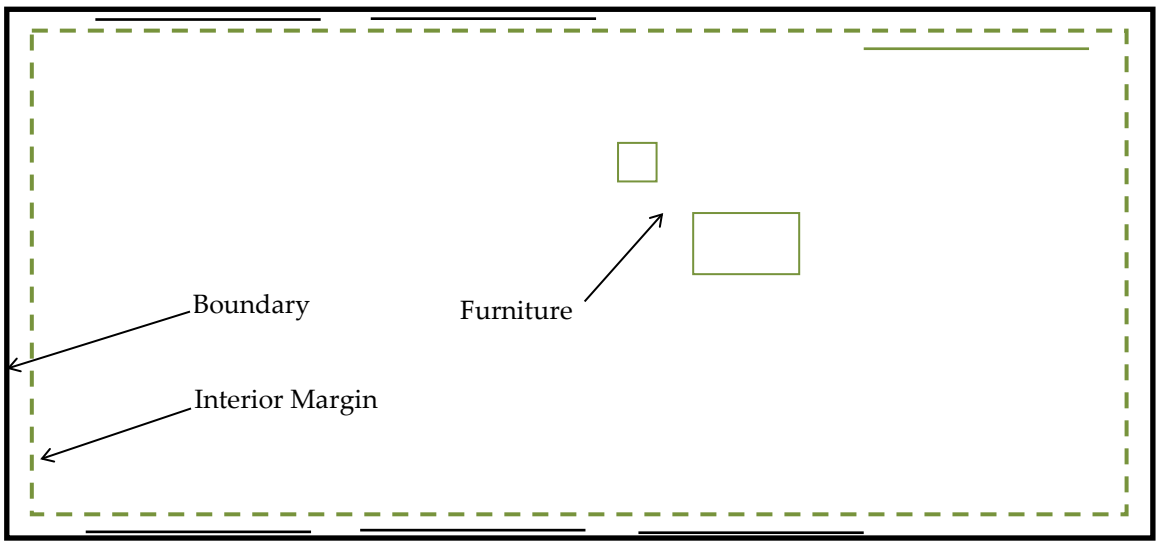
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Energy reflected from a free suspended surface given the dimensions $l \cdot w$. At high frequencies the surface reflects energy specularly (red), at low frequencies, energy is assumed to be scattered (blue). f_w is the upper specular-cut off frequency defined by the shortest dimension of the surface, f_l is the lower cutoff frequency which is defined by the length of the surface.

Boundary walls and interior margin

As long as surfaces are truly freely suspended surfaces, they will act as effective diffusers down to infinitely low frequencies. For surfaces which are elements in the boundary of the room (such as windows, doors, paintings, blackboards etc), it is not provided effective scattering down to infinitely low frequencies. From diffuser theory, it is found that the typical behaviour is that the effectiveness of a diffuser decreases rapidly below a cut-off frequency, which can roughly be defined from the depth of the diffuser (wall construction) being less than half a wavelength. At two octave bands below the cut-off frequency, the diffuser is no longer effective. At the lowest frequencies however, the dimensions of the room will provide some diffraction, therefore the dimensions of the reflecting panel as used in the formulae for f_l and f_w apply for the lowest frequencies, substituted with the approximate dimensions of the room. For frequencies in-between high and low, a combination of surface and room dimensions are used. It is worth noticing that it is not only the depth of the wall construction which enables the elements of the wall construction to provide diffraction. The angling between the surfaces, offsets e.g. the door being mounted in a door hole, or the surfaces being made of different materials, all provide phase shifts which result in diffraction. Therefore, it may be reasonable to assume that the boundary walls have a minimum depth of, say, 10 cm, in order to account for such phase shifts.



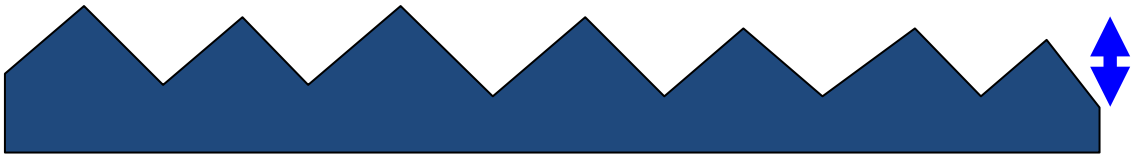
Ground plan of a room with the interior margin marked as a dashed green line. Surfaces between the boundary and the interior margin (black) provide low scattering at low frequencies, while surfaces inside the interior margin (green) provide high scattering throughout the whole frequency range.

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The typical depth of the surfaces attached to the wall such as windows and blackboards, should be specified in the Interior margin in the Room setup. ODEON will use this number in order to distinguish between interior and boundary surfaces. In case any surface is inside this margin, it will be considered as a boundary surface. Once the margin has been entered and the Room setup dialog has been closed the 3D View will display surfaces which are considered to be interior in a dark green colour, while the boundary is displayed in black. Diffraction from the boundary will be calculated taking into account that diffraction is limited towards the lowest frequencies because of limited depth of the wall constructions.

Limitations

In special cases, the *Reflection Based Scattering Coefficient* may overestimate the scattering provided by small surfaces which are only fractions of a bigger whole, e.g. small surfaces being part of a curved wall or dome. Such surfaces should not cause diffraction due to their individual area, because the individual surfaces do not provide any significant edge diffraction. In these cases, the overestimation can be bypassed by setting the surface Type to Fractional in the Materials List, see Chapter 4. When setting the Type to Fractional, the surface area used for calculating the *Reflection Based Scattering Coefficient* is determined from the box subscribing the room, rather than the individual surface - if the construction part of which the fractional surface is part of, is considerable smaller than the 'room box' scattering, it might be underestimated and a higher scattering coefficient should be assigned to the surface.

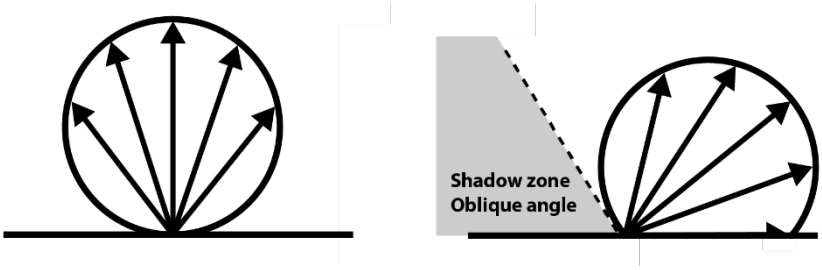


A typical diffuser depth (interior margin) entered by user, determines which parts of the geometry should be considered exterior of a room, thus limiting the scattering of the boundary surfaces which cannot be considered freely suspended at the lowest frequencies.

9.6 Oblique Lambert

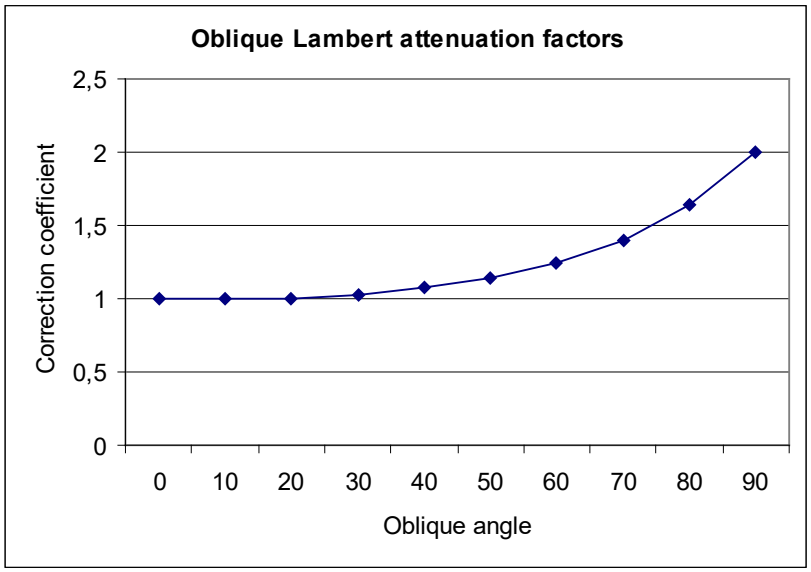
In the ray-tracing process, a number of secondary sources are generated at the collision points between walls and the rays traced. It has not been investigated yet which directivity to assign to these sources. A straight forward solution, which is the one ODEON has been applying until version 8 is, to assign Lambert directivity patterns. That is, if the diffuse area radiation is modelled via cosine directivity. The result would be that the last reflection from the secondary sources to the actual receiver point is handled with 100% scattering – regardless of the actual scattering properties for the reflection. This is not an optimal solution; in fact, when it comes to the last reflection path from wall to receiver, we know that not only the incident path length to the wall, but also the path length from the wall to the receiver are available, allowing a better estimate of the characteristic distance a^* as in the case of the ray-tracing process, where d_{refl} was assumed to be equal to d_{inc}. So which directivity to assign to the secondary sources? ODEON proposes a directivity pattern which we call *Oblique Lambert*. Reusing the concept of *Vector Based Scattering*, an orientation of our Lambert sources can be obtained taking the *Reflection Based Scattering* coefficient into account. If scattering is zero then the orientation of the *Oblique Lambert* source is found by the laws of reflection. If the scattering coefficient is equal to 1, then the orientation is that of the traditional Lambert source, and for any scattering value between 0 and 1, the orientation is determined by the vector found using the *Vector Based Scattering* method.

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Traditional Lambert directivity at the left and Oblique Lambert at the right. Oblique Lambert produces a shadow zone where no sound is reflected. The shadow zone is small if scattering is high, or if the incident direction is perpendicular to the wall. On the other hand, if scattering is low and the incident direction is oblique, then the shadow zone becomes large.

If *Oblique Lambert* was implemented as described without any further steps, this would lead to an energy loss because part of the Lambert balloon is radiating energy out of the room (notice the incomplete circle in the second figure above). In order to compensate for this, the directivity pattern has to be scaled with a factor which accounts for the lost energy. If the angle is 0, then the correction factor is 1 as no correction is necessary, and if the angle is 90° the factor becomes 2, because half of the balloon is outside the room. This is the maximum possible correction factor, and factors for angles between 0° and 90° have been found using numerical integration.



Correction factor for *Oblique Lambert*. When the oblique angle is zero, *Oblique Lambert* corresponds to traditional Lambert and the correction coefficient is 1. When the oblique angle is 90° corresponding to grazing incidence on a smooth surface, the correction factor reaches its maximum of 2.

A last remark on Oblique Lambert is that it can include frequency depending scattering at (close to) no computational cost. This part of the algorithm does not involve any ray-tracing which tends to be the heavy computational part in room acoustics prediction. Only the orientation of the Oblique Lambert source has to be recalculated for each frequency of interest in order to model scattering as a function of frequency.

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9.7 Diffraction over screens and round objects (Screen diffraction)

When no direct sound is received from a point source at a receiver position, ODEON will try to detect a one- or two-point diffraction path, using the methods suggested by Pierce in "Diffraction of sound around corners and over wide barriers" (Pierce, 1974). By only calculating the diffracted contribution when the point source is not visible, the contribution can be added to the impulse response without considering the phase-interaction between direct sound and the diffracted component, just like the reflections are added to the impulse response. Only diffraction from one edge of the diffracting object is taken into account, the one with the shortest path-length. The edge of diffraction is considered infinitely long. More information and validation is found in (Rindel, et al., 2009).

By using the algorithms by Pierce, rather than simpler ones, ODEON is capable of handling more complicated objects than the single surface screen, e.g. objects such as book shelves, the corner in e.g. a L-shaped room and buildings out-doors or diffraction over a balcony front edge, or over the edge in an orchestra pit.

Estimating diffraction points around objects

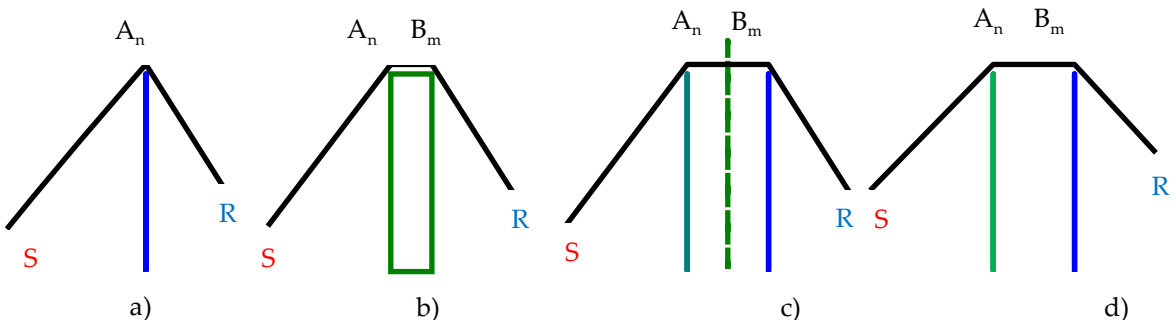
In order to calculate diffraction, it is essential that the diffraction path is established. In rooms with moderate complexity, it becomes virtually impossible for the user to describe which surface edges will act as diffracting edge, and therefore ODEON has a built-in detection algorithm. In order to limit the complexity and time consumption of the detection, there are some limitations to the type diffraction paths ODEON can detect. In order to understand the limits, here is a short description.

When a source is not visible from the receiver, ODEON will try to detect the shortest diffraction path from source to receiver in the following way:

1. A ray is sent from source towards the receiver and the first surface hit is registered (A)
2. A ray is sent from receiver towards the source and the first surface hit is registered (B)

A diffraction path should follow the path Source-A_n-B_m-Receiver, where A_n and B_m are the n^{th} and m^{th} point on an edge of each of the surfaces. The shortest path with full visibility between the three sub paths; Source-A_n, A_n-B_m and B_m-Receiver is used for the further calculations.

In cases where there are other surfaces which block the paths between one of the sub paths, ODEON will not detect a diffraction path.



Diffraction paths and their detection. a) Odeon detects a 1 point diffraction path over a thin screen. b) Odeon detects a 2 point diffraction path over a wide barrier. C) Odeon fails to detect a diffraction path because the path from A_n-B_m is obscured by a third surface – in fact it's a 3 point diffraction path. d) Odeon detects a diffraction path over two thin barriers.

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Contribution from diffracted sound over a screen, around a corner or around a book shelf, is not likely to change results noticeably. However, in rooms such as an open plan office with very absorbing ceiling or in outdoor situations, diffraction around edges may play an important role.

9.8 Radiated rays from a source

In ODEON (Combined and Industrial version only) three different kind of sources are available; the point source, the line source, and the surface source.

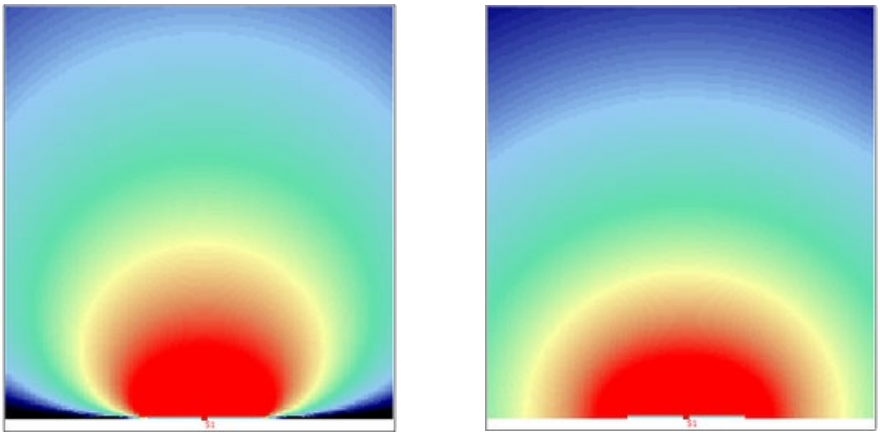
Point Sources

For Single, Multi and Grid response calculations (and for the 3D Investigate Rays and 3D Billiard displays) rays are radiated in directions distributed as evenly as possible over a solid angle. To obtain the even distribution, rays are emitted in directions given by the Fibonacci spiral. Using a spiral also ensures that there will be no preference towards (or away from) e.g. horizontal rays as might be the case if rays were radiated from a number of e.g. horizontal rings. For Quick Estimate and Global Estimate, the radiated directions are chosen randomly, allowing the calculation to be finished after any ray, without getting a very uneven distribution of radiated directions.

Surface Sources and Line sources (Industrial and Combined versions only)

For these source types, points of origin for the rays and their initial directions are the same, no matter the calculation type. For each radiated ray, a *random* point or origin point is chosen at the line or surface source. From this point the ray is sent out in a random direction, and two types of radiation can be chosen: *Lambert* and *Spherical*. When Lambert is chosen, the strength of each ray is proportional to the cosine of the angle between its direction and the normal. Practically, rays radiated parallel to the surface have zero strength, whereas rays perpendicular to the surface will carry the maximum of the energy. Spherical radiation introduces uniform strength to the rays, regardless of their direction.

Lambert radiation is preferable for ordinary surface sources, such as noise emission from machinery. *Spherical* radiation is recommended when several point sources are modelled as a surface source, instead of modelling each one individually (e.g. many people distributed over a large canteen hall). *Spherical* radiation is also a good option for modelling traffic noise, which can be considered as a dense array of vehicles, acting as individual point sources.



Lambert (left) and spherical (right) types of radiation, applicable to line and surfaces sources.

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9.9 Processing reflection data for auralisation in Single Point Response

A typical point response calculation in ODEON includes from 100.000 to 1.000.000 reflections per source/receiver. The reflections are calculated in terms of time of arrival, strength in 8 octave bands and angle of incidence (azimuth and elevation). The information on size of the reflecting surfaces and absorption coefficients are also available as a part of the calculation.

Binaural filters for headphone playback: When the Auralisation setup|Create binaural impulse response file is turned on, reflections are processed in order to create a binaural impulse response (BRIR). First of all it is determined whether a phase shift should be applied to the reflection, based on surface size and absorption coefficients of the last reflecting surface (Rindel, 1993). The reflection is filtered/convolved through 9 octave band filters (Kaiser-Bessel filters, the ninth being extrapolated) and finally the reflection is filtered/convolved through two corresponding directional filters, one for each ear (Head Related Transfer Functions), creating a binaural impulse response for that reflection. This process is carried out for each reflection received at the receiver point, superimposing all the reflections as a result; the Binaural Room Impulse Response (BRIR) for that particular receiver point is obtained. The actual order in which the filtering is carried out in ODEON, differs from the description above (otherwise the calculation time would be astronomic), but the BRIR results contain the full filtering with respect to octave band filtering in nine bands, as well as directional filtering.

Calculation of B-format filters for external decoding and Surround filters for loudspeaker playback is based on the Ambisonics technique which is covered in (Gerzon, 1992; Bamford, 1995; Malham, 2005; Furse). Most of the specific steps in involved in the generation of these filters are similar to those used for generation of BRIR's. HRTF's are not used in the calculation, since it aims at loudspeaker representation where the listener will receive reflections from the head and torso.

9.10 Calculation method for Reflector Coverage

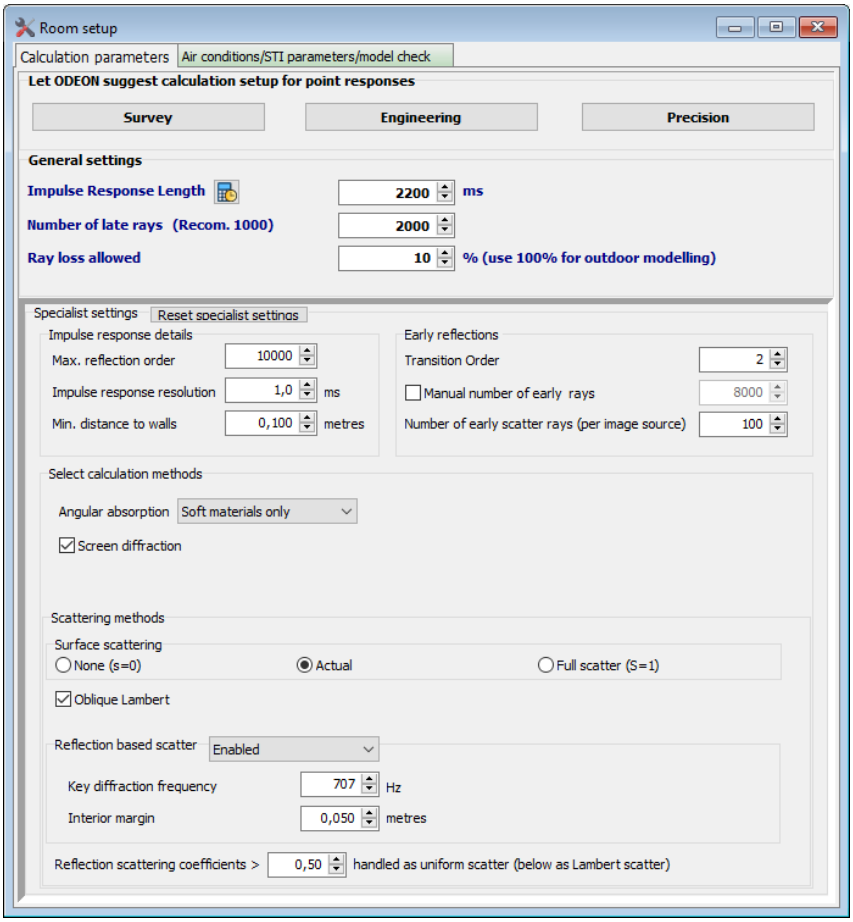
25.000 rays are sent out from the selected source, and if the rays hit one of the surfaces defined as reflector surfaces at the Define reflector surfaces menu, a cross is painted where the reflected rays hit the room surfaces. Note that the value of the Transition order is taken into account; if it is zero and the Lambert scattering is active, the chosen reflectors will show a degree of scattered reflection corresponding to their scattering coefficients. Sound from line and surface sources will include scattering upon reflections, if the Lambert scattering is on.

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10 Calculation Parameters

The calculation parameters specify how calculations are carried out in ODEON. As a starting point, ODEON suggests values that may be considered suitable for most calculation parameters, but please be aware that they may not apply perfectly to every situation, e.g. in a room with strong decoupling effects or very uneven distribution of absorption more late rays will be needed (explained in more detail further below), and in a room with strong focusing a transition order higher than 2 is suggested. Select one of the pre-sets: Survey, Engineering or Precision, which represent different levels of quality of results. ODEON will adjust the calculation parameters accordingly. You can always adjust the calculation parameters further manually. There are a couple of parameters in the General settings which should always be adjusted the Impulse response length and Number of late rays. The Specialist settings normally don't need to be adjusted.

There is more information on how to setup calculation parameters in the help file. Find it in ODEON by pressing F1 when the Room setup window is open.



10.1 Impulse response length (Job calculations and Global Estimate)

The Impulse response length should always be specified. It should be at least 2/3 of the longest reverberation time over all 1/1 octaves. It determines how many milliseconds of "decay curve" are to be calculated. It is a key parameter - if it is shorter than approx. 2/3 of the reverberation time in the room, then T_{30} cannot be calculated (because the dynamic range of the decay curve is less than

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35 dB), instead results for T_{30} will be displayed as *.** in result displays. For reliable results, it is recommended to use an Impulse response length which is comparable to the estimated reverberation time. To get an estimate of the reverberation time in a room, use the Quick Estimate available in the Materials list. The maximum allowed Impulse response length is 200000 ms. It is tempting just to use a very long impulse response length in order to avoid that reverberation time is not calculated at some frequencies – however using a length many time the expected T_{30} may harm quality of results because the very late and unreliable decay at say -200 dB will be included in the regression line from which T_{30} and other reverberation parameters are derived.

10.2 Number of late rays (Job calculations)

The Number of late rays influences the density of reflections in the late part of the decay. Having too few late rays is a very typical cause of errors, but on the other hand more late rays will extend the calculation time.

In the Room Setup, ODEON can suggest a number of rays for a survey, engineering or precision calculation. The number is derived taking into account the aspect ratio of the room as well as the size and number of surfaces in the geometry. In short, this means that ODEON will suggest more rays for very long room with many surfaces, than for a basically cubic room with few surfaces.
The suggested number of rays will be sufficient for many rooms, however in some cases more rays may be needed in order to obtain good results (please read further down for an explanation).

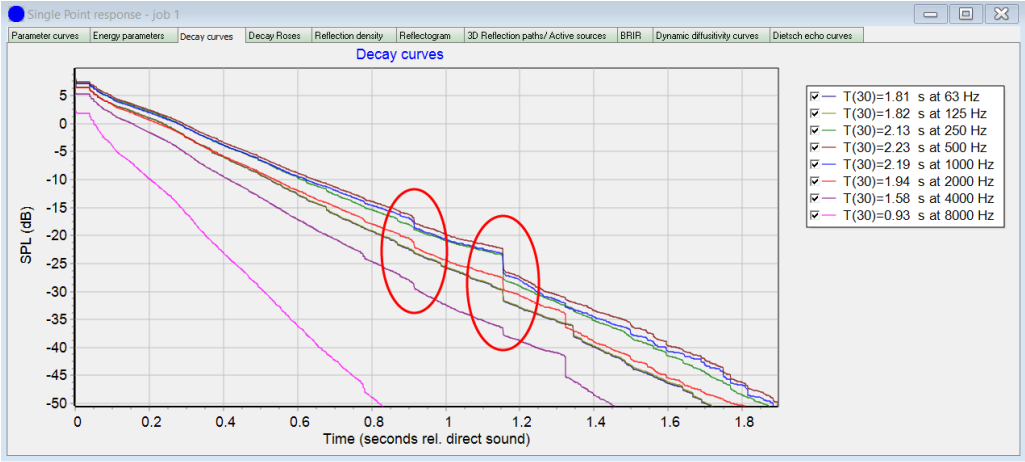
The ODEON algorithms are hybrid methods based on the Image Source Method and Ray-Radiosity for the early part of the energy, and Ray-Radiosity for the later part of energy. Therefore, there is also a Number of early rays parameter, which will be described later.

More rays needed?

There is no definite way of telling if more rays are needed for a specific calculation, but to get an idea there are some good tips.

A good thing to investigate is the decay curves. For all editions, a decay curve can be derived in the Global Estimate in the top menu. And for ODEON Auditorium and Combined, a decay curve is always calculated in the Single point response results.

If a decay curve has suspicious spikes/drops you may try to increase the number of late rays. Please see the graph below. This can also be caused by other effects, and be a part of the actual acoustics, but for most cases it is a sign of too few rays used.



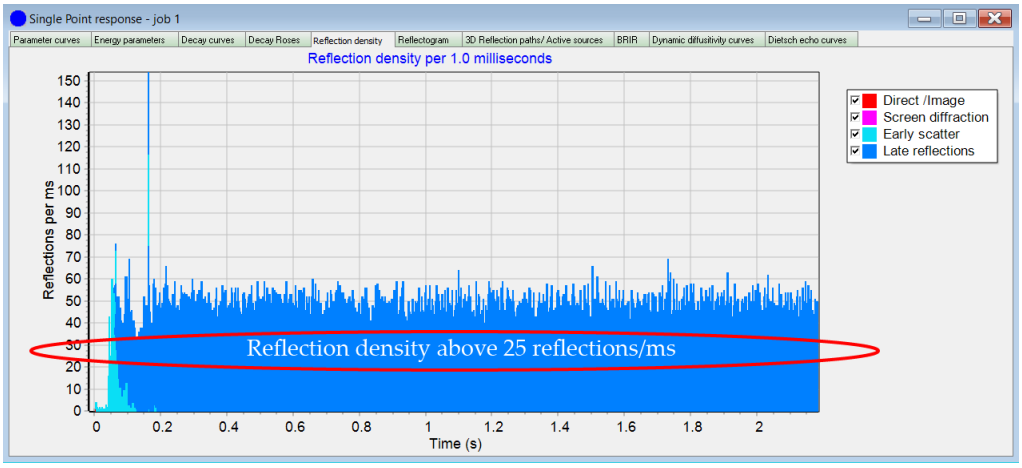
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It is also worth checking if the Global Estimate stabilizes slowly or the global decay demonstrates a 'hanging curve' effect. A rule of thumb is to let the Global Estimate run until the decay curve seems stable, then use, say, between 0.1-1 times the number of rays used in the Global estimate to specify the number of rays to be used in the calculation of the point responses (specified in the Room setup).

It is a good idea to experiment with different Number of late rays and study the decay curves in Single Point Responses. If many surfaces are added to a model, in-between calculation, it is recommended to re-specify the Number of late rays too.

ODEON also includes a tool to investigate the actual number of reflections per millisecond used in the calculation of a point response. The tool is called Reflection density and it is included in the calculated parameters of the Single point, Multi point and Grid response results. The Reflection_density parameter is included and set to Visible in the Room Acoustics Parameter List.

Additional to the numerical value, a graph like the one shown below is displayed in the Single Point response in the job list.



For reliable results, the reflection density parameter (Reflection_density) should be higher than 25 reflections/ms, as explained further below.

What could affect the numbers of rays needed

If the room model contains strong decoupling effects or uneven distribution of the absorption, it is recommended to increase the Number of late rays, even if the calculated reflection density seems high enough. Other complex geometry could also increase the needed number of late rays.

1) Strong decoupling effects: If a dry room is coupled to a reverberant room, then more rays may be needed in order to better estimate the coupling effect. An example could be a foyer or a corridor coupled to a classroom. If the room where the receiver is located is only coupled to the room where the source is located through a small opening, then more rays are also needed.

2) Very uneven distribution of the absorption in the room: In some rooms the reverberant field in the x, y and z dimensions may be very different. An example of this could be a room where all absorption is located on the ceiling while all other surfaces are hard. Another example could be an open-air theatre (modelled as having a ceiling with 100% absorption). In particular, if surfaces are all orthogonal while having different materials in the x, y and z dimensions of the room and if low scattering properties on the surfaces are used, then more rays should be used.

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On the other hand, if multiple sources with similar source power are visible from all/or most receivers, then the Number of late rays can be decreased significantly.

10.3 Specialist settings

Below the General settings are the Specialist settings, which should only be adjusted if you are an ODEON expert or experimenting. One exception is if you are importing rooms from much earlier versions of ODEON, then it will be a good idea to enable Screen diffraction to make sure diffraction around screens is included in future calculations.

Impulse response details

Max. reflection order (Job calculations only)

Max. reflection order is a stop criterion which determines how many times a ray can be reflected. Under normal conditions it should be as large as possible. In that case the Impulse response length will be the actual stop criterion and the Max. reflection order is only taken into account when stopping rays that have been trapped between two very narrow surfaces. This number may be decreased if you are only interested in the very early reflections. The Maximum allowed reflection order is 10000.

Impulse response resolution (Job calculations and Global Estimate)

The Impulse response resolution is the width of the time steps in the Impulse response histogram in which the energy of the reflections is collected during a point response calculation. The histogram is used for calculation of reverberation parameters such as EDT and T_{30}. A resolution of 1 ms is recommended – in Odeon Auditorium and Combined a resolution of 1 ms allows special scale bars for Music, Studio and Speech to be selected in the 3D part of the Decay curves and the Reflectogram in the Single Point response (resolutions of 0.5, 0.25 and 0.1 ms will also allow that).

Early reflections:

Transition Order (Job calculations only)

The Transition order (TO) determines at which reflection order ODEON changes from the early Image Source Method to the late Ray-Radiosity method.

In special cases you may want to alter the parameters to conduct special investigations. E.g. to investigate a high order echo problem, you may want to increase the Transition order to get the reflections displayed in the Single point response|reflectogram display (Auditorium and Combined editions only). However, this will rarely result in better calculation results for the room acoustical parameters. In such cases create an extra copy of the room using the Files|Copy files menu and conduct the special investigations on the copy.

The Transition order applies only to point sources. The current recommendation is TO = 2 for most rooms. For rooms that are heavily packed with various fittings or rooms where no or few image sources are visible from the receivers, a lower Transition order of 0 or 1 may be used. If a Transition order of zero is selected then point responses will be calculated using Ray Tracing/Ray-Radiosity only - which has better robustness to cases where the wave front is cut into small pieces e.g. by apertures in the room - a situation which is not handled elegantly by the Image Source Method.

Number of early rays (Job calculations only)

The Number of early rays is normally best left for ODEON to decide. ODEON will estimate a Number of early rays to use in order to detect important early reflections (Image sources) based on the number and size of surfaces, the dimensions of the room as well as the user defined Transition order. It is not given that more is better.

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Number of early scatter rays (Job calculations only)

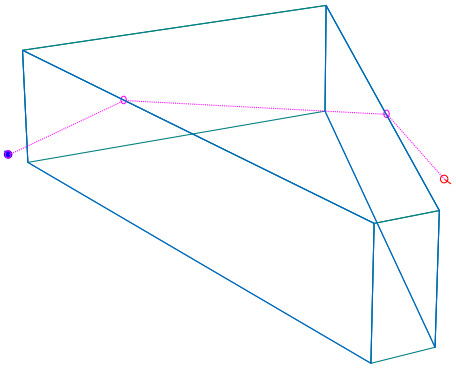
If the specified Number of early scatter rays is greater than 0, the early reflections from point sources are split into a specular part (an image source) and a scattered part (given by the scattering coefficients). 100 scatter rays (per image source) should be sufficient. The scatter rays are traced from the reflection order of the images source up to the selected Transition order.

Select calculation methods

Angular absorption (Job calculations and Global Estimate)

When this option is on, angle dependent reflection factors are taken into account. The calculation method uses the diffuse field absorption coefficients as input but generate angle dependent ones taking into account angle of incidence and the size of the surface. The method is based on the work in (Rindel, 1993). In some situations, this option does not improve the results (but on the other hand it does not seem to harm) and in many situations it means a significant improvement. Three options are available; Disabled, All materials and Soft materials only. The All materials is the thorough method whereas the Soft materials only is a trade-off between calculation time versus prediction quality. The Soft materials only method is usually almost as fast as the Disabled option and yields a quality almost as good as the All Materials method which is somewhat slower.

Screen diffraction



If this option is checked, ODEON will try to calculate the sound diffracted around objects when the source is not visible from the receiver. The diffraction method is the one suggested by (Pierce, 1974). This method includes one and two-point diffraction, allowing diffraction over or around single surface screens, wedge shaped screen and two-sided objects. The Screen diffraction is only carried out for the primary source (not for its image sources) when it is not visible from the receiver. Screen edges are detected automatically by ODEON and the shortest path around an object is used for the calculations. For more information on methods and limitations please see Chapter 3. If one or more diffraction contributions are included in a point response, they can be viewed as part of the Single point response>3DReflection paths when all reflections are displayed (A-shortcut).

Surface scattering (Job calculations, Global Estimate and Quick Estimate)

If Surface scattering is set to Actual, all directions of late reflections are calculated using the scattering coefficients assigned to the surfaces in the Materials list or according to the reflection based scattering method (see below). If the scattering coefficient is 10%, then the vector of new ray direction will be calculated as 90% of the specular vector plus 10% of the scattered vector (random direction due to the Lambert distribution). If the Scattering method is set to None (s = 0), scattering is not taken into account, thus all reflections are calculated as specular. If the surface scattering is set to Full scatter (s = 1) all surfaces will scatter 100%. The Full and None scattering methods are **NOT** recommended except for educational or research purposes.

Oblique Lambert

The Oblique Lambert method allows frequency dependent scattering to be included in late reflections of point response calculations - this option is recommended.

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Reflection Based scattering

The Reflection based scattering method automatically takes into account scattering occurring due to geometrical properties such as surface size, path lengths and angle of incidence. The use of this method is recommended unless that part of scattering has already been included in the scattering coefficients assigned to the room's surfaces.

Interior margin

By default, the typical geometrical offset in the boundary of the room is 10 centimetres. Surfaces which are closer to the boundary surfaces of the room than the distance specified by the Interior margin will also be considered boundary surfaces - this means that surfaces such as doors and windows which may be modelled as being slightly on the inside of the boundary walls, will still be considered as boundary surfaces. Interior surfaces are displayed in a green colour (teal) in the 3D View whereas boundary surfaces are black, so a change to the Interior margin will be reflected in this display when the Room setup dialog is closed. This measure tells ODEON that the effective scattering provided by boundary room surfaces should be restricted below a frequency derived from this measure. To get an idea of our suggestions to this value please look into the geometries supplied with the installation of ODEON - whether a value of 10 or 20 centimetres is chosen may not be critical, but for rooms with a very 'jumpy' boundary it should be considered to specify this parameter.

Key diffraction frequency

In order to obtain the best result in the mid-frequency range for speech and music, the default diffraction frequency is 707 Hz. This is the frequency at which diffraction is calculated for the ray-tracing part of calculations. All other parts of point response calculations take into account frequency dependent scattering. This frequency should only be changed in special cases where the focus is on another frequency range.

Scatter coefficients > x.xx handled as uniform scatter

From published material on measured scattering coefficients, there seems to be a general trend that modest scattering tends to be area based whereas high scattering is better represented by uniform scatter. In ODEON, small scattering coefficients below a certain value referred to as "x.xx", is handled either with the Lambert Oblique or Lambert algorithms, whereas scattering coefficients above x.xx are handled using uniform scattering. Scattering coefficients in the context above are the Reflection Based Scattering coefficients (if that option is activated); a typical result of this algorithm is that reflections close to an edge will be handled with uniform scattering which is desirable. Through empirical studies we have found that x.xx = 0.5 yields best results. If using a value of 0, then all reflections are handled uniformly, and if using a value of 1, then all reflections are handled using Lambert or Lambert Oblique as was the case in ODEON 8.0 and earlier.

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11 Achieving Good Results

The following chapter discusses how to obtain good results and indeed what is a good result. This is not a straight answer on how to obtain the best result, but merely a discussion that may provide some ideas as to what can be done in order to obtain reliable results in a program such as ODEON.

11.1 What are Good Results

The desirable precision - subjective limen

Before discussing how to achieve good results, it is a good idea to outline just what a good result is. The subjective limen (or "just noticeable difference" - *JND*) on room acoustical parameters should give a good suggestion as to the desirable precision. If the error between the 'real' (measured with some precision) and the simulated room acoustical parameter is less the one subjective limen, then there is no perceivable difference and there would be no need for more precise results. In some cases, it will be difficult or even impossible to obtain results at this precision, but in most of the cases, being slightly above 1 JND will still be satisfactory.

Parameter	**Definition** (ISO 3382-1, 2009) **and** (IEC 60268-16, 2011) **for STI**	Subj. limen
T_{30} *(s)*	Reverberation time, derived from –5 to – 35 dB of the decay curve	5 % rel.
EDT (s)	Early decay time, derived from 0 to – 10 dB of the decay curve	5 % rel.
D_{50} *(%)*	Deutlichkeit (definition), early (0 - 50 ms) to total energy ratio	5 % abs.
C_{80} *(dB)*	Clarity, early (0 – 80 ms) to late (80 ms – ∞) energy ratio	1 dB abs.
Ts [ms]	Centre time, time of first moment of impulse response or gravity time	10 ms abs.
G (dB)	Sound level related to omni-directional free field radiation at 10 m distance	1 dB abs.
LF (%)	Early lateral (5 – 80 ms) energy ratio, $\cos^2$(lateral angle)	5 % abs.
STI (RASTI)	Speech Transmission Index	0.03 abs.

Room acoustical parameters and their subjective limen as given by Bork (Bork, 2000) and Bradley (Bradley, 1986).

Example 1:

If the real *G* value is 1 dB and the simulated is 1.9 dB then the difference is not noticeable.

Example 2:

If the real *LF* value is 12 % and the simulated is 17 % the difference is only barely noticeable.

Note! When comparing measured parameters to the ones simulated it should be kept in mind that the measured parameters are not necessarily the grand truth as there are also uncertainties on the measured result. These errors are due to limited tolerances in the measuring equipment as well a limited precision in the algorithms used for deriving the parameters from the measured impulse response (or similar errors if results are not based on an impulse response measuring method). There may also be errors due to imprecise source and receiver positions.

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11.2 Sources of Error

There are many sources of error in a room acoustical simulation, leading to results which are less than perfect (within one subjective limen). Sometimes this is quite acceptable because we are just interested in rough results, at other times we are interested in results as good as possible. In any case, being aware of the sources of error may help getting the best possible results out of ODEON. The sources of error (or at least some of them) are:

- The approximations made in the ODEON calculation algorithms.
- Inappropriate calculation parameters (e.g. number of late rays).
- Imprecise material absorption coefficients.
- Imprecise material scattering coefficients.
- Not accurate or optimal geometry definition for use in ODEON (e.g. too detailed).
- Not accurate measured reference data to which simulations are compared.

Approximations made by ODEON

It should be kept in mind that algorithms used by software such as ODEON are only a rough representation of the real world. In particular, the effect of wave phenomena is included in the calculations only to a limited extent. There is very little to do with this fact for you, the user, except to remember that very small rooms and rooms with very small surfaces are not necessarily simulated at high precision.

Optimum calculation parameters

A number of calculation parameters can be specified in ODEON. These settings may reflect expected reverberation time, a particular shape of the room or a trade-off between calculation speed and accuracy.

Number of Late rays

Too few rays used in simulations is a very common reason for errors. Please read about how to find a reasonable number of rays in Chapter 10.2.

> A short explanation:
> ODEON by default specifies a suggested Number of late rays to be used in point response calculations. For some rooms however, this number of rays will be too low. The rooms could be coupled rooms, or rooms with very uneven absorption. A good way to test if the number of rays is sufficient, is by inspecting the decay curves as shown in section 10.2.

Transition order

The Transition order is less often a source of error, but in very detailed models it can be. The Transition order applies only to point sources. Current recommendation is TO = 2 for most rooms. For rooms with a high level of geometrical detail, with many small surfaces or rooms where no or few image sources are visible from the receivers, a lower Transition order of 0 or 1 may be used. Please read about Transition order in Chapter 10.3.

Materials/absorption data

Wrong or imprecise absorption data is probably one of the most common sources of error in room acoustic simulations. This may be due to lack of precision in the measurements of the absorption data, limitations in the measurement method itself, or because the construction material in the model was assumed based on guesswork – in any case it is a good idea to remember this and to estimate the size of error on the material data as well as the impact on the simulated results. It has been observed that absorption coefficients outside the range 0.05 to 0.9 should be used with care

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(Christensen, et al., 2008). In the Material list in Odeon, there is a button which will limit the range of absorption coefficients assigned to surfaces in a room to a selected range.

Solution if materials' data is uncertain:

There is really not much to do about the uncertainty of material data if the room does not exist, except taking the uncertainty of the materials into account in the design phase. If the room does indeed exist and is being modelled in order to evaluate different possible changes it may be a good idea to tweak uncertain materials until the simulated room acoustical parameters fits the measured ones as good as possible.

In ODEON 13 the Material Optimization Tool based on genetic algorithms was introduced. An initial estimate of materials is required. Then the algorithm searches for the best set of absorption coefficients, by a genetic evolution process, which makes simulations match better with measurements. See Chapter 13.

Absorption properties in a material library are often assumed by users to be without errors. This is far from being the truth. For high absorption coefficients and at high frequencies the values are probably quite reliable. However, low and even mid-frequency frequency absorption data and absorption data for hard materials will often have a lack of precision.

Low frequency absorption

At low frequencies the absorption coefficients measured in a reverberation chamber are with limited precision because:

- There are very few modes available in a reverberation chamber at lowest frequency bands.
- Low frequency absorption occurs partly due to the construction itself rather than its visible surface structure. Often it may not be possible to reconstruct a complete building construction in a reverberation chamber, and if reconstructing only a fraction of the wall in the reverberation chamber it will have different absorption properties, because it becomes more or less stiff.

Hard materials

Hard materials such as concrete are often listed as being 1% or 2% absorbing. It may sound like a difference of 0.5% or 1% is not a significant difference. However, if a room is dominated by this material (or one of the dimensions of the room is), a change from 1% to 2% is a change of twice as much absorption!

Materials/scattering coefficients

The knowledge on scattering coefficients is currently rather limited. Hopefully in the future, the scattering coefficients will be available for some materials. Meanwhile the best that can be done is to make some good guesses on the size of the scattering coefficients and to do some estimates on the effect of uncertainty. Please read Chapter 4.

Measurements

The reference data which you may use to compare simulated room acoustical parameters against, is not guaranteed to be perfect. We must accept some tolerances on the precision of the measured parameters.

Receiver position(s)

Common errors are:

- to base the room acoustic design on simulations in one or only few receiver positions.
- to place the receiver close to a surface.
- to use too short source-receiver distance.

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Source-Receiver distance

Point response calculations made in ODEON are to be compared with point response measurements and as such the (ISO 3382-1, 2009) standard should be followed:

To obtain good estimates of reverberation time, the minimum source-receiver distance should be used in order to avoid strong influence from the direct sound. The minimum source–receiver distance according to ISO 3382-1 is:

$$d_{\min} = 2\sqrt{\frac{V}{c * T}} \quad \text{(m)}$$

where :
V is the volume of the room (m^3).
c is the speed of sound (m/s).
T is an estimate of the expected reverberation time (s).

Thus, for a typical concert hall a source-receiver distance less than 10 metres should be avoided in order to get good predictions (measurements) of the reverberation time.

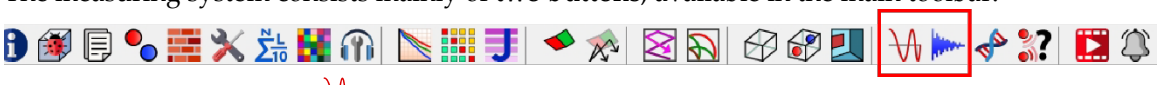
Minimum distance from the receiver to the closest surface

If a receiver is placed very close to a surface, then results will be sensitive to the actual position of the secondary sources generated by ODEON's late ray method. If such a secondary source happens to be very close to the receiver, e.g. 1 to 10 centimetres, this may produce a spurious spike on the decay curve, resulting in unreliable predictions of the reverberation time – indeed if the distance is zero then in principle an infinitely large contribution would be generated. To avoid this problem, it is recommended that distances to surfaces are kept greater than, say, 0.3 to 0.5 metres. Anyway, for other reasons, it is recommended to keep distances greater than a quarter of a wavelength, i.e. 1.3 metres at 63 Hz. A distance of 1 metre is required by ISO 3382.

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12 Measurement System

A measurement system is integrated in all editions of ODEON. It helps to obtain the impulse response of real rooms, loudspeakers, headphones and other acoustic systems. You can either measure or import an impulse response, and from it, the *decay curves*, the *room acoustic parameters*, and many other relevant quantities are calculated.
The measuring system consists mainly of **two buttons**, available in the main toolbar:

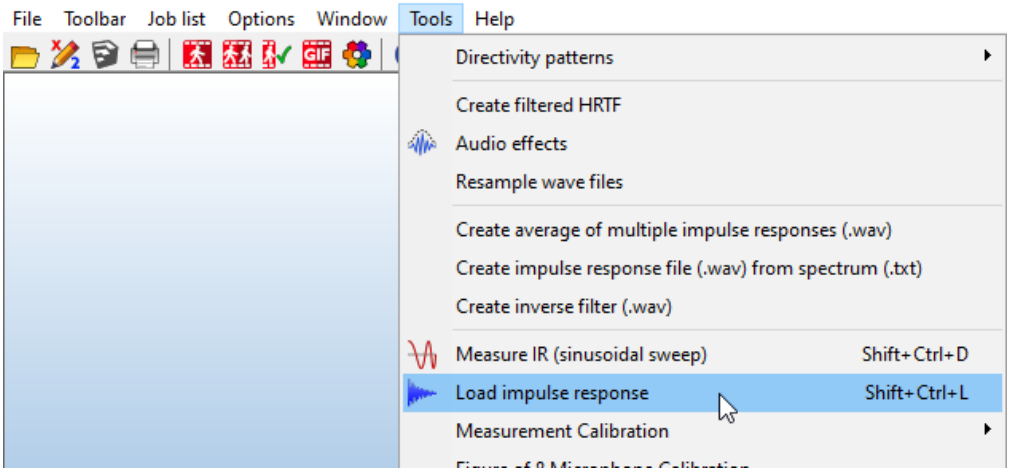


- **Measure impulse response** . It makes an impulse response measurement using the measurement system in ODEON. The measurement system uses the sine sweep method, being very effective to suppress background noise and getting accurate results. To use this option, you need at least a speaker and microphone.
- **Load impulse response** . It loads an impulse response stored on your computer. This can either be a measurement made using ODEON or similar software measurement software, or it can be a sketch measurement just using a hand clap or balloon with a handheld recorder like a phone.

These buttons are always active, whether or not a room has been opened. The Room Acoustic Parameter List button always remains active as well, in order to make it possible to edit parameters that are displayed in the Load impulse response window (there are limited options in the Basics & Industrial edition).

Note: The measuring facilities in ODEON can be used as a stand-alone tool without any associated room model. You can record, load, edit and store impulse responses without having to perform any simulation.

In addition to the two main buttons, several relevant tools can be found under the Tools menu from the main menu bar:



What is an Impulse Response and a Sine Sweep

An impulse response is the output of a system when the input is an impulse. Mathematically, an impulse is considered to contain all frequencies, therefore the impulse response contains the full behaviour of the system. In room acoustics, the system is the room, the input was traditionally a hand clap or a balloon pop, and the output is the obtained recording. However, these inputs are only rough approximations to a true impulse, and are not as accurate compared to modern

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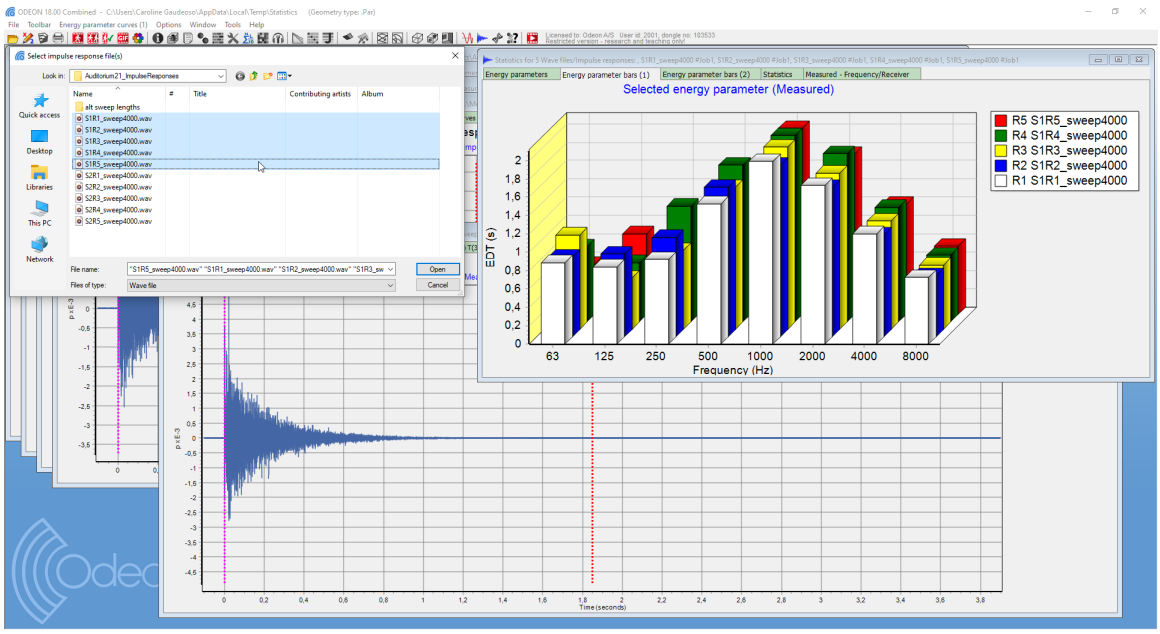
measurement methods like the Sine Sweep (Müller, 2001). In the sine sweep, the frequencies are played one sine tone at the time, and ODEON then translates this into an impulse response. This is explained in more detail later. You can still use the hand claps or balloon recordings with ODEON, but we call these "Sketch Measurements" and recommend to use the Sine Sweep method with ODEON if accuracy is important.

Standalone measurement system

If no room is loaded, most buttons, are grayed and inactive, except the ones for the measuring system, plus the button that leads to the video tutorials page.



In this mode you can only use ODEON as a standalone measuring system. You can either measure a new impulse response with the Measure impulse response interface or load impulse responses with the Load impulse response function. See further down in sections 12.3 and 12.4 for a detailed walk-through.
If you load more than one impulse responses (SHIFT/CTRL files in the Select impulse response file(s) dialogue), a statistics window will be displayed automatically, with various results displayed in the same manner as in Job List>Multi-point Response.



Compare simulations and measurements

Generally, the use of the measuring system goes beyond to be just a standalone tool. One of the strongest parts of having a measuring system inside ODEON is the possibility to compare measurements with simulations. If a room is loaded, measurements and simulations can be displayed side by side at the same time for easy comparison of results, as ODEON aims at displaying measured and simulated results in similar graphical ways.

You can transfer measured room acoustics parameters to the Multi point response display available in the Job List, facilitating comparison of measurements and simulations. See how in Section 12.6.

Remember: ODEON functions both as a room acoustics simulation software as well as a room acoustics measurement software. You can compare measured with simulated results in the Multi point response display.

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Sketch Measurements

If you are not bringing the full set of measurement equipment (PC, amplifier, loudspeaker etc.), you can record a hand clap, the popping of a balloon or a paper bag, or even the gunshot of a start gun, e.g. using a smart phone with an application that supports recording wave files or a dedicated portable audio recorder. The clapping hands will act as the *source* and the phone/recorder will act as the *receiver-microphone*. The files containing impulse responses can be loaded into ODEON using the Load impulse response button. As the energy of a handclap is limited, ODEON may not be able to derive energy at all frequency bands (in particular lower ones) due to background noise – but still this may be better than nothing. You can read more on how to make a sketch measurement in the application note **Measurements with a Smart Phone**.

12.1 Technical Background

This is a chapter on the technical background of the measurements system, and for the basic user it is not necessary to know to such detail how to do measurements.

High Quality Measurements Using the Sweep Method

The room impulse response measurements in ODEON can be performed using linear and exponential sweep signals, which is superior to other methods in suppressing background noise, leading to high Signal-to-Noise ratio (Müller, 2001) and high immunity to distortion. A sweep is simply a pure sinusoidal signal, with frequency increasing monotonically in time. The sweep method for measuring impulse responses is the least sensitive method to time variance and distortion and it is expected to work well on most hardware systems. ODEON uses sweeps to excite a room and record the response to this signal at a microphone (receiver) position in real time. This sweep response is then deconvolved to give the impulse response between the source and the microphone. This process uses upward sweeps, instead of downward, meaning that low frequencies are played first. The energy of low frequency sound typically takes more time to decay than the energy of high frequency sound in a room. Therefore, upward sweeps are preferable over downward ones, in order to ensure that the decay of low frequencies is captured within the recording of the whole sweep response, and harmonic distortion is suppressed. An extra decay period of a few seconds is recorded after the end of the sweep, so that the remaining decay for middle and high frequencies can be completely captured.

Octave Band Filtering

The broadband impulse response obtained by the sweep method is filtered in octave bands between 63 Hz and 8 kHz, using 2nd order Butterworth filters, according to the IEC 61260 (1995-08) standard. These analog Butterworth filters are implemented by digital Infinite Impulse Response filters (IIR filters), which introduce unwanted transients in the beginning of the response.
Although the length of the impulse response of the filters is infinite, a finite effective length is used, so 99.9% of the energy of the filtered response is included. The length of the transients in the filtered response is considered equal to the effective length of the filter. Moreover, reversed filtering is applied for decay analysis so that all the transients appear at the tail of the impulse response, instead of the beginning, and the filter phase distortion is suppressed. ODEON automatically excludes the transient tail when processing the impulse response.

Detection of Direct Sound

An ideal impulse response, according to geometrical acoustics (Kuttruff, 1973), would consist of an ensemble of Dirac impulses with appropriate delays and strengths. The ideal direct sound from a source should be a perfect Dirac impulse too, arriving at a time equivalent to the distance between the source and the receiver. However, in reality the direct sound and all the other reflections are not perfect Dirac impulses. In fact, each reflection consists of an onset and some decay. As the

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frequency gets lower, the decay of a reflection may overlap with the onset of a subsequent reflection. In the derivation of many of the ISO 3382 parameters it is vital to capture the amount of early energy correctly. ODEON uses advanced algorithms for successfully detecting the energy from the direct sound and discriminating it from the following reflections. For every impulse response the correct onset time is indicated in the display. According to the ISO 3382 standard (ISO 3382-1,2008) the onset of the direct sound and of the whole impulse response should be counted at least -20 dB below the peak level of the direct sound. This dB value is called Trigger level. In many cases a lower value for the Trigger level may be desirable and this is the reason why this is an adjustable parameter in the ODEON measuring system.

Detection of Noise Floor

Most of the impulse response recordings, whether recorded directly or obtained using the sweep method, come with a noise tail, due to the ambient background noise and noise of the transmission line involved (PC sound card, cables and microphone). This noise tail should be excluded before deriving the decay curve and the ISO 3382 room acoustic parameters (ISO 3382-2, 2008). The ODEON measurement system utilizes a modification of the algorithm by Lundeby for automatically detecting the noise floor and truncating the impulse response at an appropriate time (Lundeby A, 1995).

12.2 Equipment to use with the Measurement System

The ODEON measuring system is very flexible to work with different setups. The equipment can vary from very simple and light to more complicated setups. Nowadays, the simplest version consists of an Odeon Omni wireless loudspeaker and a USB microphone connected directly to a lap-top PC (Figure 12-1). In this case, both the input (microphone) and output (Odeon Omni) devices use their own built-in sound cards which are of high quality, sufficient for all room acoustic measurements.

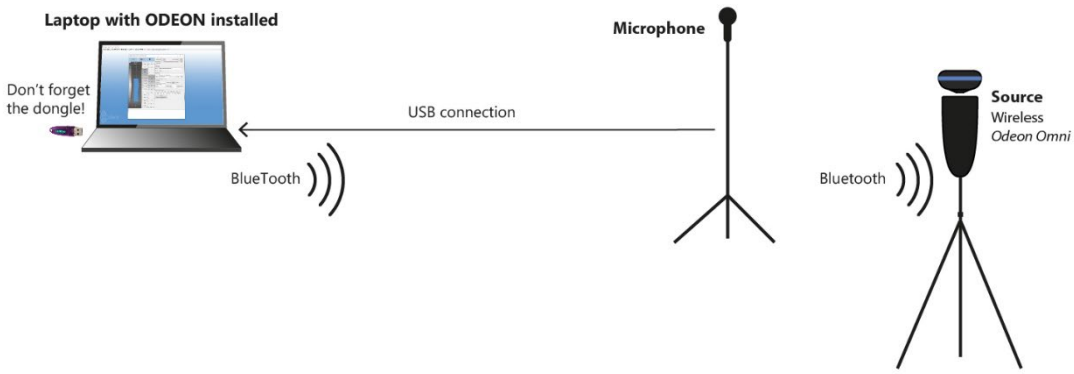


Figure 12-1: The lightest possible measuring setup for ODEON measurements consists of a wireless Odeon Omni and a USB microphone. The setup is highly portable encouraging faster and more frequent measuring sessions, especially in medium-sized to smaller venues.

The more traditional measurement setup would consist of cabled connections with or without an external sound card/audio interface (Figure 12-1). This setup is typically harder to transport, because it requires more components, such as an amplifier for the source and pre-amps for the microphone, usually present in a high-quality external audio interface. However, the benefit of the traditional setup is the possibility to use sources that are more powerful than *Odeon Omni* for the largest venues and for building acoustics measurements.

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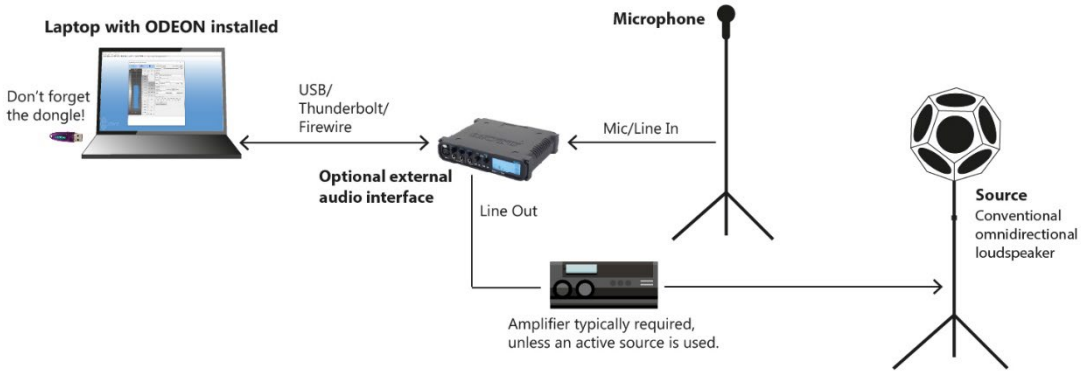


Figure 12-2: Traditional measuring setup, using cabled connections for the microphone and source. This setup requires typically more components, such as an amplifier for the source and/or an external audio interface with pre-amps for the microphone.

Microphone

A microphone is used to record the impulse response at a specific 'receiver' location. Many types of microphones are suitable for our purpose, and choosing any of them is a matter of budget, ease of use and precision. One of the most important prerequisites is that the frequency response is as flat as possible for the octave bands between 63 Hz and 8000 Hz. If using the built-in microphone amplifier, it has a (mixer) slider which should be set to max manually by the user.

Microphone type

According to the technology used, microphones can be divided in *Condenser*, *Electret*, *Digital* and *Dynamic* ones.

Condenser microphones have an ultra-light diaphragm and are extremely sensitive to soft sounds, therefore are *the ideal type for room acoustic measurements* in order to capture even the weakest reflections in the room. These microphones require *phantom* (external) power, typically **12V** or **48V**, which is often provided by external sound cards (audio interfaces).

Electret microphones require a steady electric charging (supply) to activate them. Their diaphragm is light enough to vibrate with subtle sounds, therefore they have high sensitivity and are highly suitable for room acoustic measurements. Usually, the electric charging comes from an internal battery, although some models can accept *phantom* power from the audio interface.

Dynamic microphones are the least sensitive type. They consist of a diaphragm that can be excited by sound waves and start vibrate. The movement generates electric signals which are then transmitted into the rest of our equipment. Such microphones do not require electricity to operate, but since they do not have high sensitivity, amplification is typically required to boost the recorded impulse response in the room. Another characteristic is their typically large diaphragm which makes the whole microphone big and not as close to an ideally 'point' receiver. Therefore, dynamic microphones are not the best for room acoustic measurements.

Microphone class

The class defines how accurately the microphone records sounds. **Class 1** is more accurate than **Class 2**, because it allows less tolerance (deviation) of sound level at the different octave bands.

For example: *At 1kHz*, **Class 1** microphones have tolerance +/- 1.1 dB, while **Class 2** ones have tolerance +/- 1.4 dB. *At 20 Hz*, **Class 1** microphones have tolerance +/- 2.5 dB, while **Class 2** ones have tolerance +/- 3.5 dB.

Somebody can find a full comparison of the two Classes in the **IEC 61672-1:2002** standard. However, for room acoustic measurements in ODEON, the class is not crucial, simply because all room acoustic parameters are derived for each octave band independently and without taking into

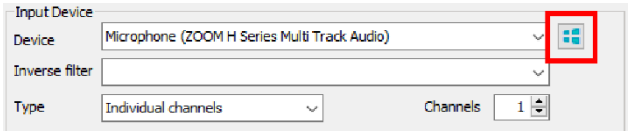
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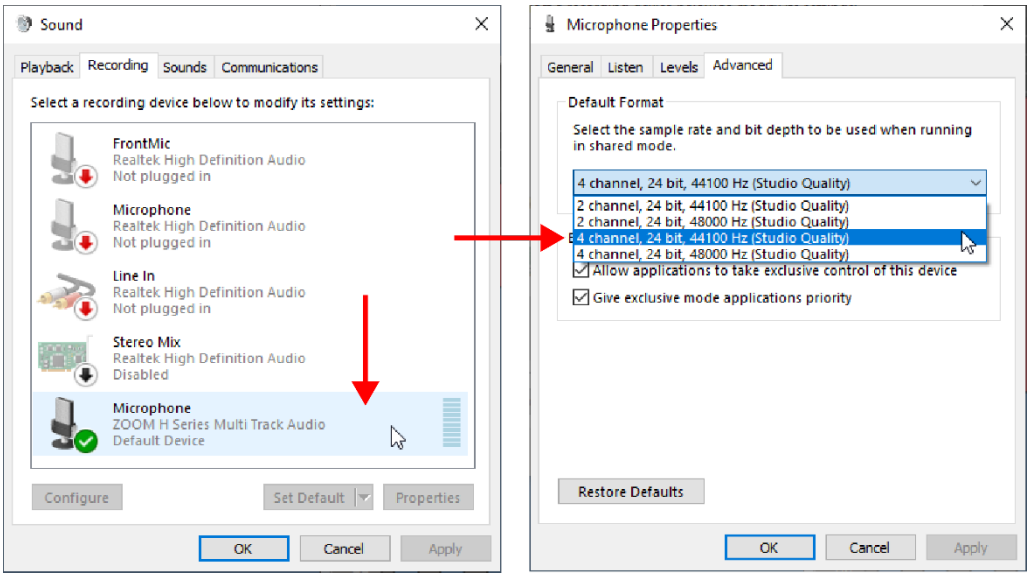
account the actual sound level that is recorded by the microphone, as long it is well above the background noise. Even for parameters like *Sound Strength* G, the measuring system has to be calibrated (see Section 12.9). Therefore, any imprecisions of the microphone will be included automatically, as correction factors, in calibration.

Ambisonics (B-format) Microphone

Since ODEON 16, 4 input channels can be recognized when a 1st order ambisonics (B-format) microphone is connected. Various conventions exist for the order of the 4 ambisonics channels, but ODEON recognizes the **FuMa** (*Furse Malham*) convention (please read more in the ODEON help, in the *Auralisation Setup*). The microphone should be connected to a sound device that encodes the 4 channels directly into W, X, Y, Z, according to the **FuMa** convention. ODEON does not perform the encoding. The first channel W is always the omni one.

In case the 4 channels are not recognised by ODEON Measurement settings, make sure you have enabled it in the microphone properties from your computer. Click on the windows icon, choose the ambisonics microphone and enable the 4 channel option with the sampling rate matching with the ODEON settings.





Setting microphone amplification

It is not uncommon to have a dedicated microphone amplifier (boost) which can typically be set in the range 0 to 30 dB, and if so, be sure to set it so a desirable response is achieved (for sufficient SNR). If using a different setting in your measurements than those used in the calibration, be sure to adjust the external adjustments in the measurement setup accordingly.
Often, the sound card (the audio interface) – described just below - offers sufficient microphone amplification. Most modern sound cards are equipped with **phantom power** to be used with **condenser microphones**. It is worth checking the capabilities of your sound card and whether they are sufficient for your microphone requirements, before investing in an expensive dedicated microphone amplifier.

Source (loudspeaker)

A flat frequency-response loudspeaker source can help to obtain enough Signal-to-Noise ratio (SNR) for as many as possible octave bands.

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The loudspeaker should also be as omnidirectional as possible, according to the specifications in the ISO standard 3382-1 (ISO 3382-1, 2009). As reported in the standard, the source should be able to produce a sound pressure level sufficient to provide decay curves with the required minimum dynamic range, without contamination by background noise.

Some loudspeakers come with a built-in amplifier (active loudspeakers). They can be very useful as no external amplification is needed.
When the source has no internal amplification (passive source) an external amplifier is needed.

Sound Card / Audio interface

External sound cards/audio interfaces can always be used in connection to the output/input devices, however modern *built-in sound cards* of a portable PCs (laptops) are of adequate quality for room acoustic measurements with ODEON. Both their dramatic hardware improvement in the past decade, as well as ODEON sweep measuring algorithms ensure measurements of very low distortion, so that external interfaces are not necessary. This makes the overall equipment simpler and lighter.
However, an external audio interface offers greater flexibility, providing more precise gain adjustments, support for different cable types (e.g., XLR, TRS), and the ability to connect multiple microphones for multi-channel measurements. In many cases, it is also required to supply amplification for the microphones via the built-in preamps.
Brands like *Focusrite*, *Motu*, *RME* and *Behringer* produce external sound cards of decent studio quality, well-suited for room acoustic measurements as well, in a wide range of budgets.

Setting up your sound card correctly

Set up your sound card correctly for use with the ODEON measurement system. Many sound cards are equipped with advanced features such as *noise cancellation*, *echo cancellation*, *reverberation*, which may be useful when using internet/video conferencing or listening to music. However, such features are highly undesirable when using the sound card for room acoustics measurements, thus they should be disabled.
For example, many PCs come with the built-in Realtek audio device. You can access the global settings for this device within from the Realtek Audio Manager. The noise suppression and echo cancellation options for the recording device (microphone) should be deactivated.

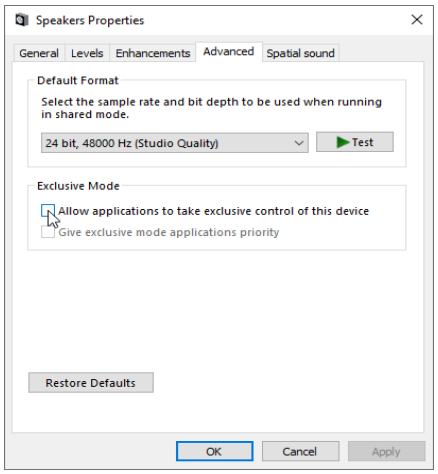
SNR of sound card and microphone

The sound equipment you use for measurements (sound card, microphone and amplifier) should provide a decent Signal-to-Noise ratio (S/N) – otherwise you will need long measurement times in order to suppress background noise caused by the equipment. In principle, the longer the sweep signal, the higher the suppression of the background noise. For every doubling of the sweep length a suppression of background noise by 3dB is achieved. However, even if over-prolonging the sweep can be an option, it is far more convenient to record at shorter times with a better SNR from your equipment, in order to avoid accidental noise interfering during the measurement.

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General recommendations

Disable system sounds in mixer



This is important so that no disturbing sounds are suddenly played during a measurement. Since ODEON 15, the measuring software makes use of the Windows Audio Session Programmers Application Interface (WASAPI) which allows better measurement quality. It bypasses the Windows Kernel Mixer, thus avoiding noise from other audio devices and applications on the PC, as well as the low-quality re-sampling of the Kernel Mixer. This also allows recording in *Exclusive mode* by default.

However, please note that it is not possible to activate *Exclusive mode* for the playback device, since several issues have been reported with different audio interfaces and devices. Therefore, the feature has been disabled in ODEON 18. *Exclusive mode* will remain disabled, even if the box 'Allow application to take exclusive control of this device' is selected in the Properties->Advanced tabsheet. See the screenshot on the right.

Other methods to record impulse responses

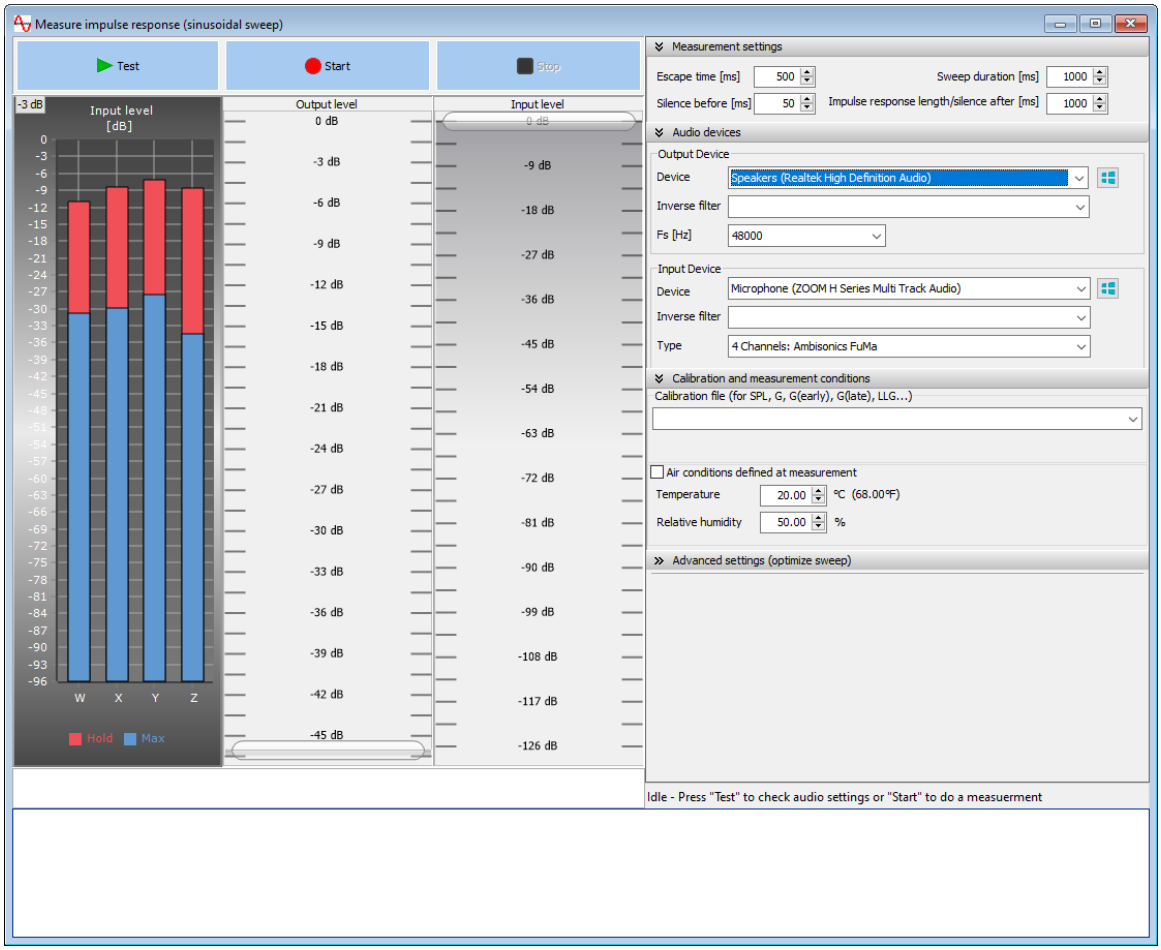
If someone wishes to experiment with some other stimuli than the sweep signals used by ODEON – such as gunshots or balloon/paper bag popping only a portable recorder is necessary. The impulse response can be recorded as a .wav file and be post-processed afterwards in ODEON.

12.3 Measurement Setup Options

Measure Impulse Response Options

The Measure Impulse Response window in ODEON provides a range of options for the measurements. Most of the options are found in the "Settings" tab in the upper right corner.

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The Measure impulse response interface.

Input Levels, Test and Start

- **Input Levels:** There are two level bars at the left side of the window. The **blue** bar shows the current level captured by the microphone, while the **red** bar shows the **maximum** (peak) value being captured so far. You can set the input and output levels with the two large sliders in the center.
- **Test:** If you press Test, the sine sweep will loop, but not record. You can change the level of the input and output, to find the correct level before making a recording or measurement. The rest of the settings will be locked, until you stop the loop with the Stop button.
- **Start:** If you press Start, an actual measurement is made, with a sweep playback and recording. After the sweep has been played, you are prompted to save the recorded impulse response file. When this is done, the decay curve and acoustical parameters are calculated and displayed.

Input/Output level sliders

You can use the sliders for the output and input levels.

- **Output:** The Output will go through your soundcard to the speaker. In order to reduce the effect of background noise, both in the room/space and from hardware, a high *Output Level* is important. But be careful not to set the level of the sound source (speaker) so loud that it starts distorting, which will affect the measurement quality. And be aware that loud noises can damage your ears, so ear protection is often necessary if you don't leave the room while measuring.
- **Input:** The input slider controls the input level of the soundcard of the microphone. In Windows, the input level in ODEON and the level in the Microphone properties window will be locked together and change simultaneously. Some soundcards will have an extra slider in the

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Microphone properties window called Boost. This will change the level, but not be registered by ODEON as a change is settings, and should only be used before the first measurement. Read more about this in the next bullet point.

> **Note:** Changing the input level can be beneficial, especially to avoid clipping, but be aware that setting a higher level rarely lowers the background noise. The microphone becomes more sensitive and it picks up not only higher signal, but higher background noise too. For lowering the background noise, use a **higher output level** or **longer sweeps**.

- **Set Levels/SPL Compensation:** You can also change the levels directly at your hardware or somewhere else outside ODEON (e.g. on the soundcard or mixing software accompanying the soundcard). However, the advantage on changing levels inside ODEON (the output and input sliders) is that ODEON will compensate for the internal changes when evaluating the results.
  For example, if you measure at the same microphone position two times with changed slider values, the SPL levels will stay the same. In other words, if you realize that the output level needs to be increased in the middle of a measurement session, you should use the internal sliders. This will ensure that the SPL variation at the different microphone positions will not be affected by this adjustment.
  On the other hand, if you change the levels outside ODEON, the software will not know about the changes, and the measurements become incomparable in terms of SPL.
  If SPL, G, or STI is part of the measurements, the levels may be changed outside ODEON only before the first measurement.
  If you have changed the level outside ODEON and know by how many dB the SPL was increased or decreased, you can compensate for this in Options > Program Setup > Measurement setup > External adjustments > Gain.

> **Remember:** The output device in the setup affects only the sweep signal during the measurement. Auralisation, both in measurements and simulations is played back though the device chosen in Windows playback devices panel.

Measurement settings

(Right part of the Measure Impulse response window)
The settings are saved when either Test or Start is pressed. If you make changes to the settings and leave the menu again without either pressing Test or Start, the changes will be discarded.

- **Escape time [ms]:** this is the time from the moment you press the button until the measurements starts. If making many loud measurements without ear protection, we recommend leaving the room to protect your hearing. This parameter gives you time to leave the room before the measurement starts, hence "escape time".
- **Silence before [ms]:** added silence before the onset time of the measured impulse response. This is applied to the resulting impulse response, not the sweep. Distortion from the speakers can be detected in this part of the file.
- **Sweep Duration [ms]:** One of the most important parameters. The longer the sweep, the lower the background noise will be. For every doubling of the sine sweep length, the background noise will be attenuated by 3 dB. The maximum allowed duration is 80 sec.
- **Impulse response length/Silence after [ms]:** this parameter corresponds both to the length of the measured impulse response and the silence recorded after the sweep. This silence is added to ensure that the late part of the recorded sweep (the highest frequencies) has enough time to decay in the room. We recommend using a duration that is longer than the expected reverberation time, so that both the sound decay and the background noise are captured in the measured impulse response.

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Remember: You should always remain silent both throughout the sweep recording and the silence after, until the measurement save dialog shows up.

Audio devices

- **Output Device**: Choose which output and sampling rate you are using for the measurements. This output needs to be connected to your speakers or sound source. The sampling rate is often controlled by the hardware used. You also have the possibility of adding an inverse filter in order to compensate for the frequency response of the source. See in **Appendix F** how to obtain an inverse filter for your device.
- **Input Device**: Choose the input device for the measurements. The input device needs to be connected to (or be itself) the microphone. You can also specify an inverse filter to compensate for the frequency response of the microphone. See in **Appendix F** how to obtain an inverse filter for your device. The input can contain more than one channel. If that is the case, the following input types are available:
  - **Individual channels:** each channel is saved as a separate impulse response measurement.
  - **Omni and Figure of 8 (2 channels):** channel 1 is an omnidirectional microphone and channel 2 is a Figure of 8 microphone.
  - **Binaural (2 channels):** the two channels are measured on both ears of a dummy head.
  - **First Order Ambisonics (4 channels):** It reads the four B-format channels W, X, Y, Z (FuMa convention), already encoded by the recording device.
    Measurements with more than one channel yield extra spatial information on the measurements, such as the spatial parameters LF_{80} and LFC_{80} and L_j (Omni and Figure of 8, First Order Ambisonics). The omnidirectional channel is sufficient in order to calculate parameters such as EDT, T_{30}, SPL, C_{50}, C_{80} etc.

The two Windows icons will take you to the windows audio output and input setups.

Note: The inverse filters are saved as wave files in the application data folder, in MeasurementFilters.

Calibration and measurement conditions

- **Calibration file:** Here you can choose a calibration file, if you have one, to add to the measurements directly. Calibration is needed to calculate SPL and strength parameters. All calibration files are stored by default inside the Application data>Calibrations folder. Only for backup purposes you can access this folder by choosing Options>Explore Application data folder.
- **Measurement conditions:** if the ambient conditions (temperature and relative humidity) are known, activate the checkbox and enter the corresponding values. This will adjust the measurement to the loaded room's conditions (specified in Room Setup) or the default ones if no room is loaded (specified in Program Setup).

Note: you can deactivate the adjustment for measurement conditions in Program Setup by unchecking "Normalize measurements to target conditions" in the Measurement Setup tab.

Advanced settings (optimize sweep)

- **Sweep Slope:** You can choose the slope type of the sine-sweep. The White (Linear) sweep has frequency energy spread equivalent to *white noise* and the spectrum is a line in logarithmic axis. The Pink (Exponential) sweep has frequency energy spread equivalent to *pink noise* and the spectrum is an exponential curve. In other words, the Pink sweep provides longer playback time for low frequencies, thus more energy at this range, while the White sweep provides longer playback time at mid and high frequencies. For most room acoustic measurements, the Pink

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(Exponential) sweep is preferred against the White (Linear) sweep. On the other hand, White (Linear) may be preferable in measurements of sound transmission between rooms, because partitions often provide attenuation at high frequencies. You can also make a manual slope, by choosing Manual and specifying the Spectrum slope in the dB/Octave box.

- **Frequency Range:** To be more time efficient, you can choose only to measure the frequency range of interest.
- **Sweep spectrum correction:** you can modify the sweep's spectrum per frequency band by entering corrections in dB. This will change the speed of the sweep as a function of frequency, while the level remains constant during the measurement. This tool can be used to enhance the measurement in octave bands with a low SNR, because of background noise or the frequency response of the speaker used for example. Note that overall, the sweep length remains the same, so the corrections are relative. For instance, boosting one frequency band will automatically reduce the power in other bands. A consequence is that very large variations across bands will only be possible for sufficiently long sweeps. If the sweep duration is too short, the variations will be truncated.
- **Automatic correction:** the button Calculate from impulse response makes it possible to correct the sweep's spectrum automatically, using a previously measured impulse response. The correction is based on compensating for the variations in the measured decay range across bands. Follow the steps described below:
  - Measure a first "pilot" impulse response with an uncorrected sweep. Save the resulting pilot impulse response.
  - Before carrying out the actual measurement, click on Calculate from impulse response and select the pilot impulse response (wave file).
  - Perform the actual impulse response measurement with the corrected sweep.
  - Note that both the pilot and the actual measurement must be carried out in the same conditions for optimal use.

Remember:

1. In order to calculate the spatial parameters LF(80), LFC(80) and Lj, you need an input that can measure spatial information (either Omni+Figure of 8 or B-format probe). If you use other types, you should uncheck the Measured option for those parameters in the Room acoustics parameters list.
2. In order to obtain meaningful values for a parameter such as SPL, it is essential that a proper Source Power Spectrum is entered (described below) and that a system calibration has been performed. If you do not perform any system calibration then you should uncheck the Measured option for SPL (and other parameters that may rely on calibration) in the Room acoustics parameters list.

Press Expand tables in the upper right corner in the Room acoustic parameters list to be able to change settings.

Tip: If during the measurement, a sudden peak causes the recording to clip, ODEON terminates the measurement showing a warning message. This way, ODEON helps you avoid storing such faulty measurement which you may not have noticed.

Other Setup Options

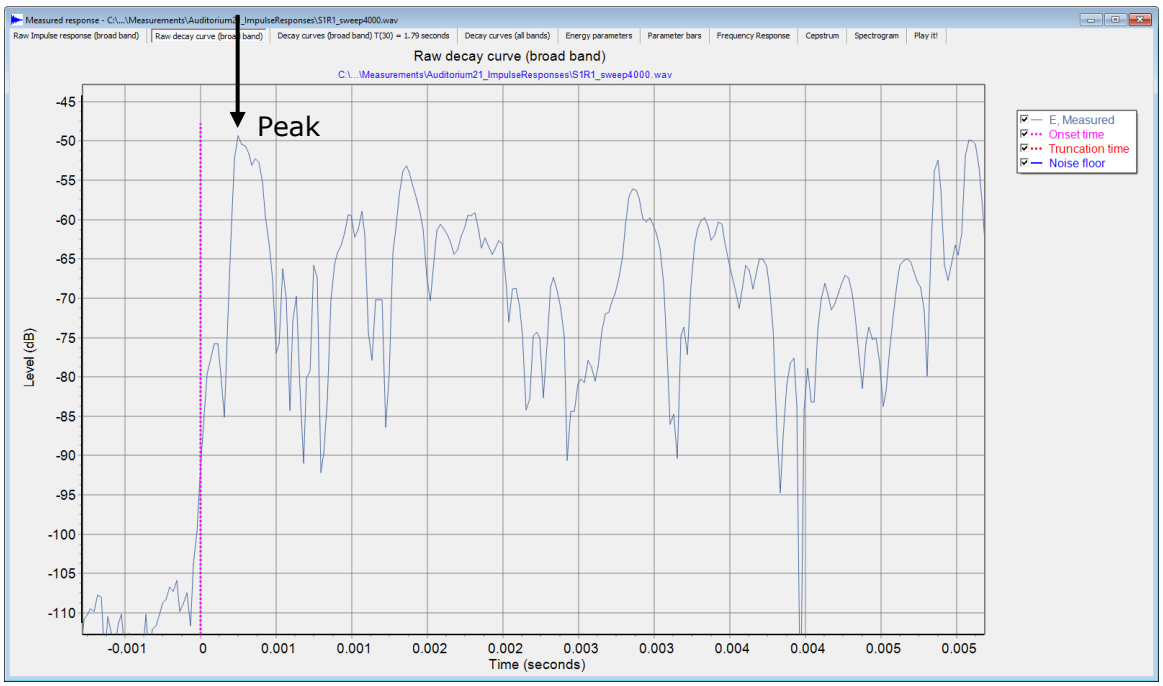
In the Options>Program setup>Measurement setup important parameters can be adjusted, concerning the measurement signal, the post processing of the impulse response, the calibration and your sound equipment.

Parameters for detection of onset time

The Noise floor window length specifies the time interval used to detect the noise floor before the onset time of the impulse response. When a sound file contains more than one impulse response in a row (e.g. hand-clap recordings in a sequence), a sufficiently short Noise floor window length is required, in

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order for ODEON to successfully discriminate the different impulse responses. In cases where magnetic feedback introduces strong spikes at the beginning of the impulse response (this measurement error happens if microphone and loudspeaker cables lie parallel and close to each other for some distance), this setting can help the user get rid of it.
The Trigger level is the level that determines the onset time of the impulse response. Since no real impulse response starts with a perfect DIRAC pulse, there is always some build-up of energy that happens before the first peak of the response. ODEON first takes the square of the impulse response so that all peaks appear positive. Then it detects the first and strongest peak of the squared impulse response and searches backwards for a drop equal to the Trigger level. The corresponding time at this level is the onset time of the impulse response. The default value for the Trigger level is -40 dB. ODEON finally shifts the whole impulse response, so that the onset time is always aligned to 0 seconds.
In the following example, a squared impulse response is zoomed-in close to the first peak, which is at around -50 dB. The onset time is shown by a vertical pink dotted line and has been located at -90 dB, that is 40 dB below the peak, equal to the Trigger level.



Detection of Onset time when loading an impulse response. By default, the onset time starts at 40 dB below the peak.

Source power spectrum

ODEON comes with two types of source power spectra that can be used with the calibration of the measuring system: A flat frequency spectrum source, called G-ISO 3382-1 and a speech spectrum source, called Speech-ISO 3382-3. The source type G-ISO 3382-1 should be chosen for almost all room acoustic cases, covered in the ISO 3382-1 (auditoria, concert halls etc.). On the other hand, source type Speech-ISO 3382-3 should be chosen if the measurement is or has been carried out in an open plan office (ISO 3382-3 standard). Apart from the default settings, the user can define a custom source spectrum.

Background noise

This specifies the absolute RMS dB value of the background noise in the room per octave band. The values are obtained from the Room setup if a room has been assigned, otherwise default values are used. The level of the background noise is used in the calculation of STI (Speech Transmission

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Index) and other parameters using noise, as well as for the ISO 3382-3 results presented in the multi-point response of ODEON.

Decay curve settings

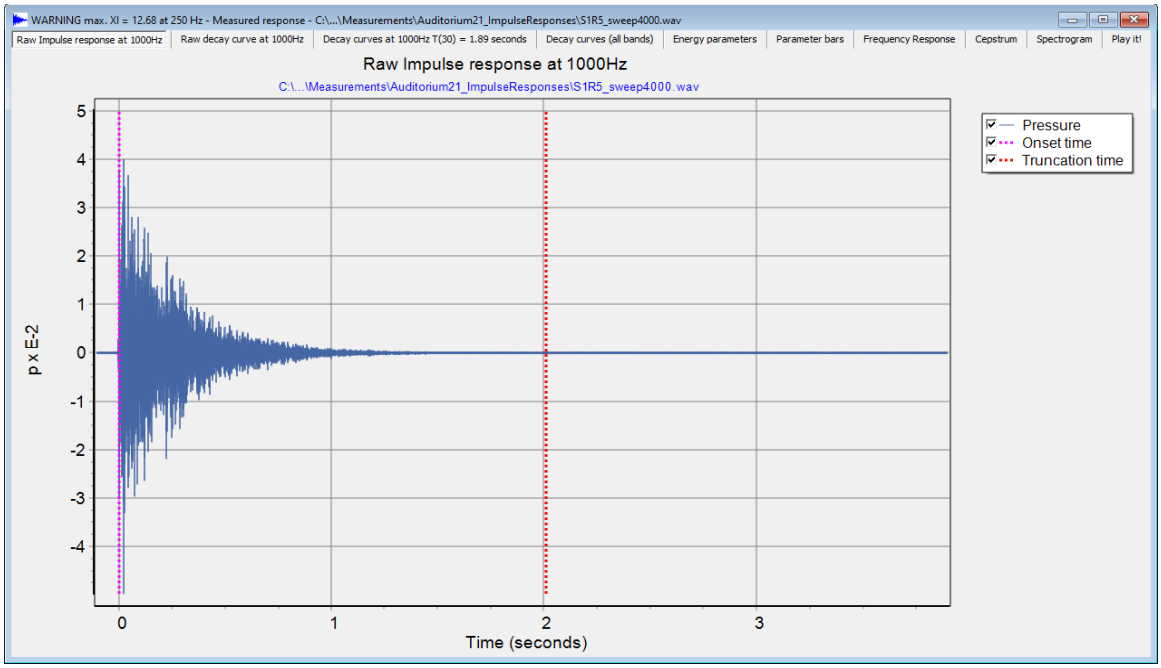
Here you can adjust the resolution of the impulse response, as it appears at the Decay curves display (see Load Impulse Response section in Chapter 12). When no room is assigned to ODEON the default setting for the resolution is 3.0 ms. With a room assigned, the value is taken directly from the Room setup, so that the measured energy response can be compared side by side to the simulated energy response obtained in the Single Point Response.

External adjustments

The overall Gain for the sweep signal playback can be adjusted here.

12.4 Load Measured Response

You can load an impulse response file in uncompressed .wav format by pressing the Load Impulse Response button or by clicking Tools>Load Impulse Response (SHIFT+CTRL+L). In principle, you can load and process any sound .wav file in the ODEON measuring system. You should be able to see even a music signal in the ODEON measuring system editor, but calculated parameters may not make any sense and the room acoustic parameters may not be calculated at all for such a file. The larger the file is the longer it will take for ODEON to open. A folder called 'Measurements' is included in the ODEON main folder where impulse responses are stored by default. High quality Impulse responses can be measured using the sweep feature in ODEON if loudspeaker, amplifier, microphone, etc. are available. It is also possible to record handclap, popping of balloon or paper bag etc. e.g. using a smart phone or a portable audio recorder, and then load the impulse response file into ODEON. If a file contains multiple impulse responses (such as hand claps) ODEON will try to make use of the one providing the best Signal-to-Noise ratio (S/N). The next figure shows a typical impulse response loaded on the Measured Impulse response window.



The Measured response window in ODEON, accessed via the Load Impulse Response button.

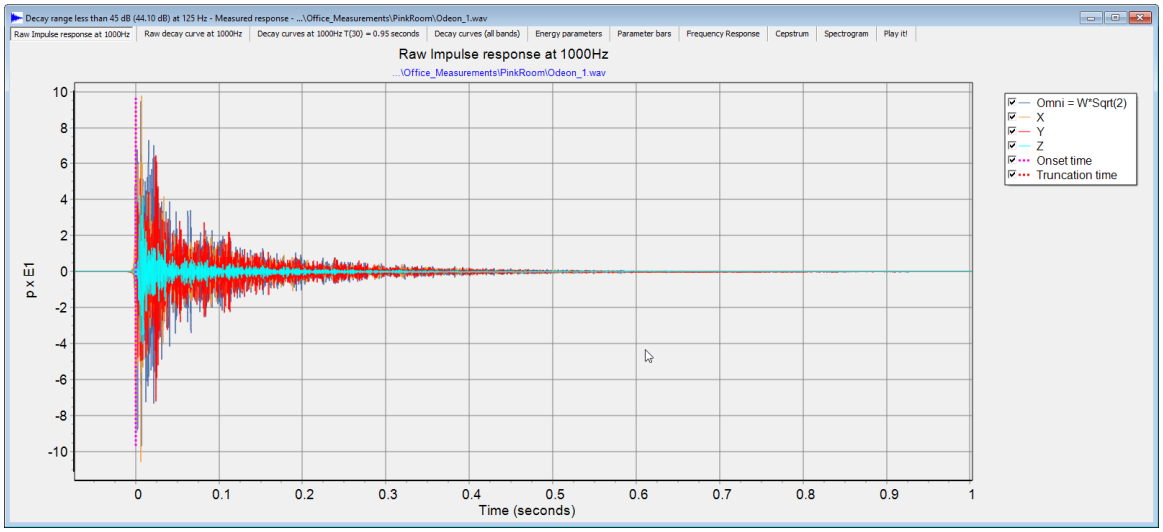
For a multi-channel impulse response, you can select its type by using the context-sensitive menu for any of the available tab-sheets. For example, a 4-channel measurement can either be used as a

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B-format impulse response or reduced to its first channel, by choosing Raw Impulse response>Change Impulse Response Type.

Loading a B-format impulse response

Since ODEON 16, four-channel B-format impulse responses can be recognized. The responses should be already encoded into the W, X, Y, Z channels. Such a response will look like in the following screenshot, with the first channel (W) being the omni, while the rest correspond to the axes of the x, y, z coordinate system (Gerzon, 1973).



All subsequent tab-sheets show results for the W channel only, while the last Tabsheet allows auralisation using all the channels. Since the B-format impulse response includes all necessary directional information, the Play it! Interface allows for adjustment of the direction of the receiver.

12.5 Results from Measurements

Raw Impulse Response

The Raw Impulse Response displays the broadband and filtered pressure impulse response. For a multi-channel measurement, all the channels are displayed in the graph. You can switch between different octave-band filters by using the Up and Down arrow keys on the keyboard. A vertical dotted purple line indicates the onset time of the impulse response. ODEON detects the strongest peak in a recording, whether this is a typical impulse response or any sound file. If the recording consists of a series of impulse responses (e.g. hand-claps), the onset time of the strongest impulse response will be detected. A vertical dotted red line, unique to each octave band, indicates the truncation at the noise floor. Whenever there is not sufficient Signal-to-Noise ratio in the impulse response recording, the truncation time cannot be determined (safely). Instead of the truncation time, the estimated end of the response is displayed, again by a vertical dotted red line.

You can zoom-in by clicking the left mouse button and dragging towards the lower right corner of the graph. In that way a zoom-in rectangle is specified between certain values of the horizontal and the vertical axes. Releasing the mouse button, the selected area is magnified to fit the whole window. Zoom out again by clicking the left mouse button and dragging it towards upper left corner.

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Remember: Navigate through octave bands by pressing the Up and Down arrows at the keyboard or by clicking next frequency band / previous frequency band in the Measured Response menu (that should be already activated in the top menu bar).

Raw Decay Curve

This is a display of the squared pressure impulse response (i.e. energy impulse response) together with the onset and truncation times. In this graph, the values of the squared pressure are in dB (re 20 μPa), which makes details more visible. However, these values will only be meaningful if the impulse response was obtained from a calibrated simulation or measurement, otherwise the decibels will be arbitrary. Similarly to the Raw Impulse Response, both the onset and truncation times are displayed. In addition, a horizontal solid blue line indicates the noise floor in the impulse response. When the noise floor of the response has a high degree of fluctuation, this solid line becomes dashed, indicating that the noise floor is far from being flat, and consequently that the estimation is not reliable.

Decay Curves

On this display the pure part of the impulse response between the onset and truncation times is processed further. Three types of curves are displayed in the graph for each octave band:

- E, Measured: This is the energy impulse response (Raw Decay Curve) between the onset and truncation times with a resolution specified either in the Room setup or the Measurement setup. The display is fully compatible with the Decay Curves displayed in the simulated Point responses in the Single Point display in ODEON Auditorium and Combined.
- E, Integrated: This is the result of the backwards Schroeder's integration of the energy impulse response between the onset and truncation times.
- E, Corrected: This is the E, Integrated curve with compensation for the lack of energy at the end of the response, which is caused by the backwards Schroeder's integration.

For a B-format impulse response, these additional curves are also displayed:

- I, Measured: This is the estimated norm of the intensity vector with the same time resolution as the measured energy. The intensity vector is calculated using the X, Y and Z channels as an estimate of the particle velocity vector.
- I, Integrated: This is the result of the backwards Schroeder's integration of the intensity norm between the onset and truncation times.

For B-format measurement, a 3D reflection view can also be opened by clicking on the button on the right of the graph. ODEON locates intensity peaks from the measured intensity curve and displays each peak as a spike in the 3D view. The length of the spike corresponds to the intensity norm, its direction is the direction of the intensity vector and its colour is related to its time of arrival. A hedgehog view displays all the intensity peaks in the time interval shown by the Decay Curve graph. You can navigate through the intensity peaks using P and Shift+P. If a room is loaded, it is possible to display the 3D visualization at the location of a receiver by selecting the corresponding job. This visualization tool can be useful for detecting strong reflections and flutter echoes.

Decay Curves (all bands)

Here the corrected energy decay curves (E, Corrected) are displayed for all bands on the same graph. You can enable/disable the different octave bands in the right-side menu.

Decay roses (A)(C)

For B-format impulse responses, decay roses display the energy decay as a function of direction, in the horizontal and vertical planes. These are similar to the decay roses obtained in Single Point Responses.

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Energy parameters

All calculated room acoustic parameters are displayed in a table of the same format as that for the single and multi/point responses (see Chapter 8).

Parameter curves

The room acoustic parameters are displayed in bar graphs. You can scroll among the different parameters by using the Left and Right arrow keys in the keyboard.

Frequency Response

Displays the frequency response (spectrum) of the whole impulse response file, including the truncated parts. Therefore, if you want to derive the frequency response of specific part you need to crop the response with the Crop Impulse Response tool, described in Sec. 12.6.

Cepstrum (A)(C)

Displays the inverse Fourier transform of the logarithm of the Spectrum (Frequency Response). The Cepstrum brings the signal from the frequency domain to a new domain with the unit seconds (or preferably ms). In order to distinguish from the time domain, the independent variable in the cepstrum is called **Quefrency**. It is noted that the terms Cepstrum and Quefrency have been made by reversing the order of the first letters in spectrum and frequency.
The cepstrum analysis is very efficient to find any periodic behaviour of the spectrum. So, a single peak in the cepstrum at quefrency Δt is an indication that the spectrum contains harmonics with frequency spacing $1 / \Delta t$. For more information about the cepstrum technique see (Rindel, 2016).

Spectrogram (A)(C)

Displays the frequency response as a function of time. In other words, it shows the level for time and frequency for the impulse response. It can help locating colouration issues including flutter echoes (where some frequencies may repeat in time).

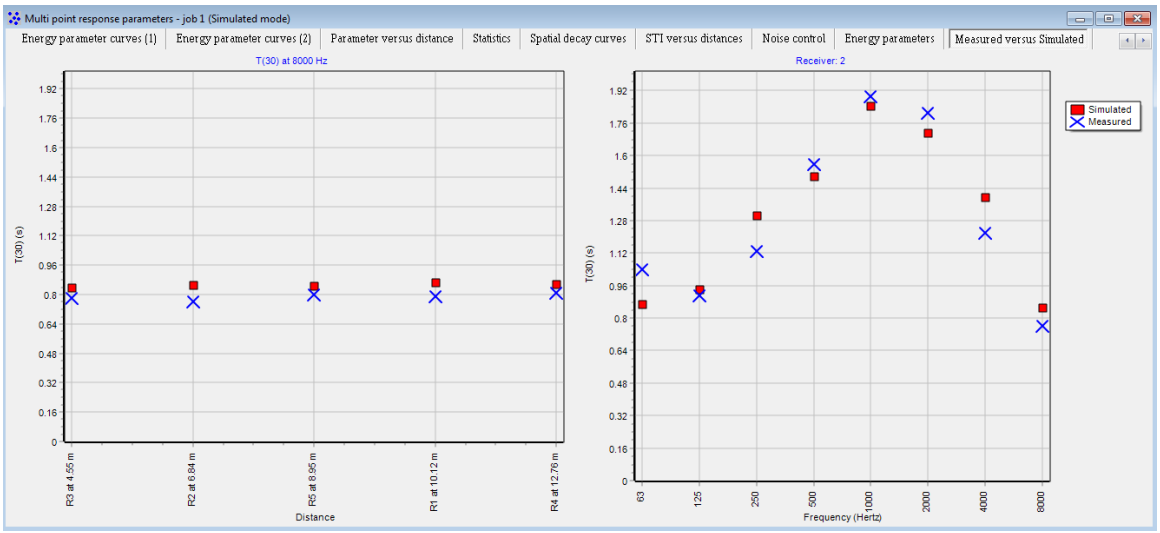
Play it! (A)(C)

Makes it possible to listen to the measured impulse response as well as to listen to a signal convolved with the same impulse response. So, one can hear how the room measured sounds at the given measurement position with the given source(s).
For B-format measurements, extra settings are shown at the lower half of the window. You can choose any wave file to convolve with the synthesized impulse response. The orientation of the listener's head can be modified in real time both in terms of azimuth and elevation. A binaural impulse response is synthesized, so the you should listen to the result with headphones.

12.6 Inserting measured room acoustics parameters into a multi-point response

If a room model has been loaded into ODEON, then it is possible to insert the room acoustics parameters derived from a measurement file which has been opened with the Load Impulse Response. Use the Add measured parameters (INS shortcut) or Add measured parameters and close (Ctrl+INS shortcut) available from the Measured response menu, and specify the appropriate job and receiver number in the dialog that appears. Once the parameters have been added, you may view them in the Multi point response (with the given job number and if the receiver number has been specified in the Source receiver list), available from the JobList, e.g. together with simulation results (see Chapter 5.2). Even if no simulations have been carried out, you may benefit from the Multi point response display as it can provide results that are related to multiple receivers (e.g., statistics) or results according to the new ISO 3382-3 standard on open plan offices. You can toggle between simulated and measured mode in the Multi point response by pressing the M key. The figure below shows an example of measured and simulated T_{30} in the Multi point response.

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Simulated and measured reverberation time T_{30} inside the Auditorium 21 at the Technical University of Denmark. The graph on the left shows the values at all receivers for a given octave band, while the graph on the right shows the values at all octave bands for a given receiver. Press the Up and Down arrows to change frequency. Press R to change receiver.

Since ODEON 18, it is also possible to add room acoustics parameters from multiple impulse responses at once for a more efficient workflow. In the Job list menu, click on Add measured data from impulse responses to multi-point jobs and select your impulse responses (.wav) in the Open Dialog. In order to speed up the process, no confirmation dialog is displayed. This means that you should make sure that the quality of the impulse responses has been verified already, and that onset and truncation times have been modified if needed.

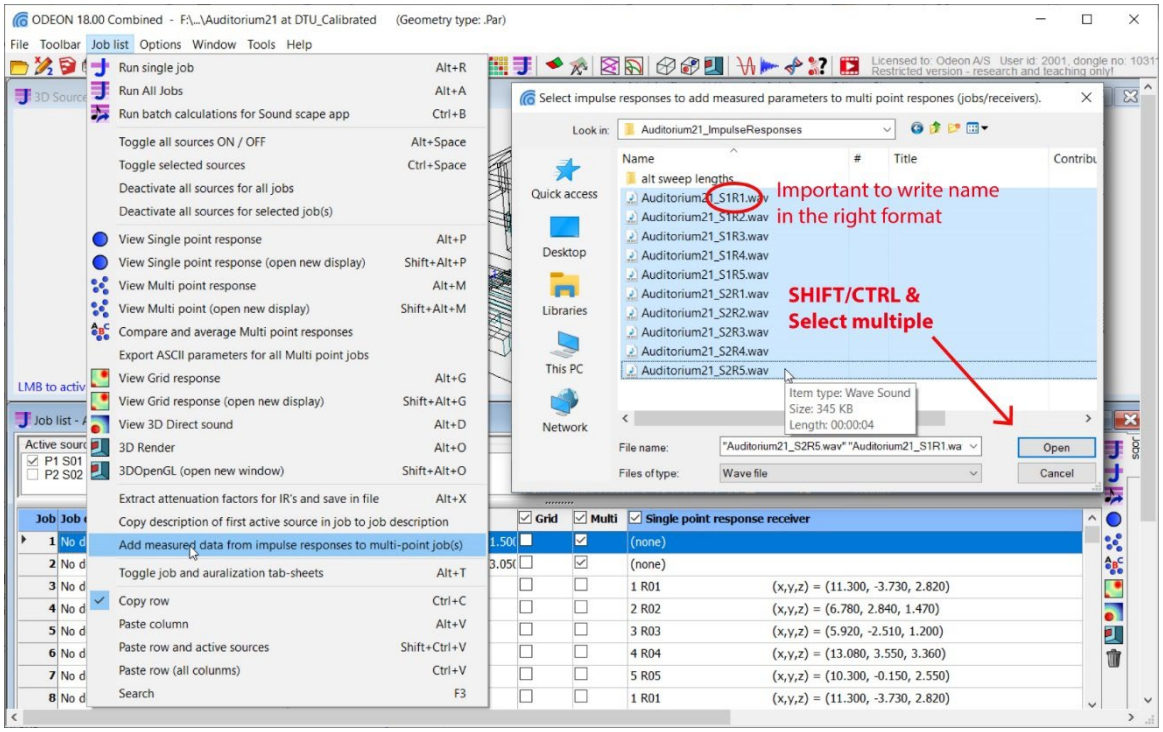
The matching of impulse response room acoustics parameters with the receivers and jobs is based on the file names. Therefore, the end of your file names should follow the syntax <Text><XX><Text><YY>.wav, where XX indicates the job number and YY the receiver number. The text in both brackets can be anything (from letters to words), but it is really recommended to follow a good practice of writing a meaningful symbol before each number, so that it is easy to identify the file in your folder.

- Some suggestions for the text before the job number are: S/Job/Source/Kilde/Loudspeaker, preceded by a file name describing the measurement (eg. the room name, the date etc.).
- Some suggestions for the text before the receiver number are: R/Receiver/Modtager/Microphone.

Example of a valid file name:

- **RoomNameS1R1.wav**. This will be matched to Job 1 and Receiver 1. See the following screenshot for an example.

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Examples of invalid file names:

- **RoomNameS1R3_SweepLength4000Sec.wav**. This will fail to be matched properly, because the file name ends with text instead of a number.
- **RoomNameS2R4_SweepLength4000.wav**. Even if the file name ends with a number, this doesn't correspond to a meaningful receiver. ODEON reads the file name from left to right. Therefore, it will try to match 4000 as the receiver number and 4 as the job number. It will then ignore any number after that (S2).

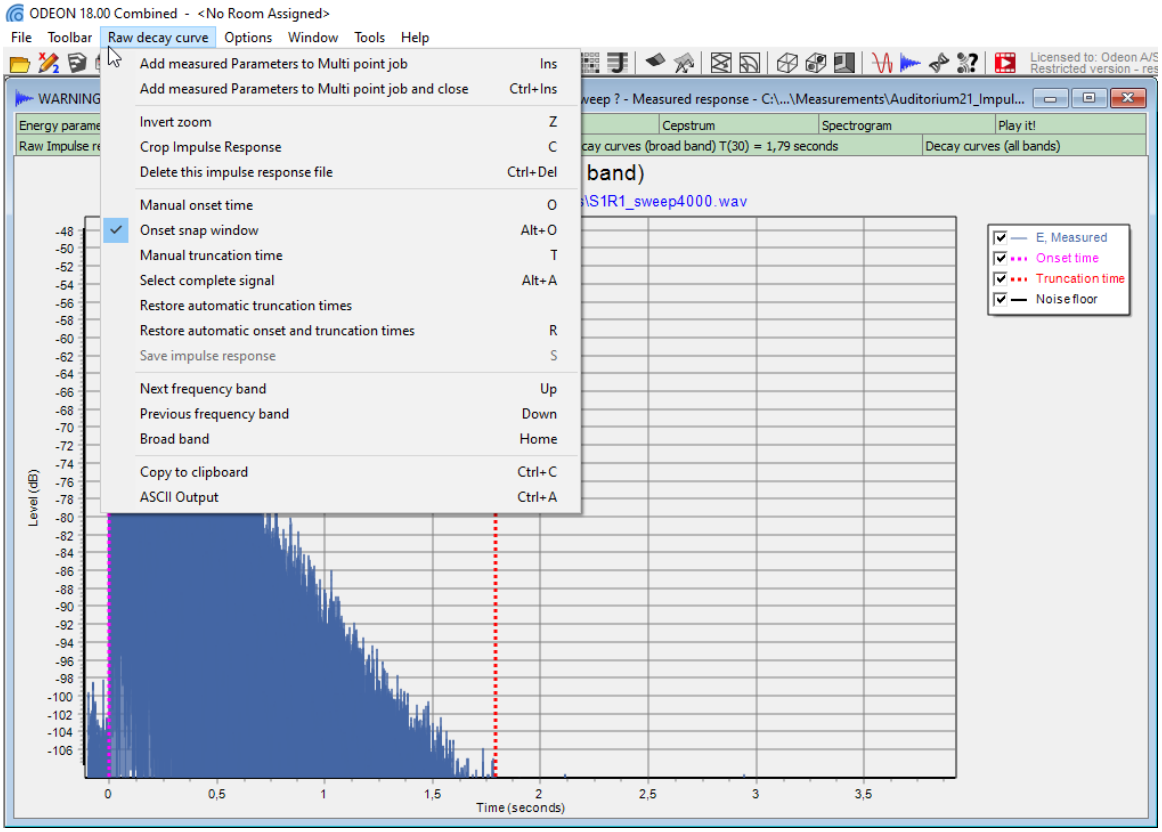
12.7 Editing Impulse Responses

Three functions are available for editing an impulse response. Cropping, Manual onset time and Manual truncation time. All these options are available in the first two tab-sheets: Raw impulse response and Raw Decay curve.

Tip: The Raw Decay curve display is more convenient for editing an impulse response as all values have been converted to dB, leading to a better view of the dynamic range. In addition, all reflections become positive (same phase) and they are displayed in the upper part, making it easier to decide what is the beginning and the end of the response.

In the next figure it is shown how to access the editing functions from the context-sensitive menu on the main menu bar. See below for analytic descriptions of the editing functions.

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Click on the Measured Response menu to see all available tools for editing and other functions.

Cropping

To crop an impulse response, click the left mouse button, hold down and drag a rectangle around the part you want to crop. Release the mouse button. ODEON now zooms the cropped part to occupy the whole window. Choose Measured Response>Crop Impulse Response (C shortcut). Now the part will be saved as a new .wav file. Odeon asks you to choose a file name and confirm. By default, the name of the original file is suggested, but make sure to rename it first, if you want to keep the original file.

Manual onset time

In most cases the automatic onset time by ODEON is totally acceptable. However, since ODEON 13 it is possible to decide on your own onset time. Choose Measured Response > Manual onset time (O shortcut). The mouse cursor becomes a *cross* symbol when hovering on the impulse response. Click anywhere on the impulse response to define a new onset time for the current frequency band. If needed, zoom the area of interest by dragging a rectangle from top left to right bottom (to zoom out drag the opposite way). The pink dotted line defining the onset time moves now to the new point. If Onset snap window is active the onset time tends to snap at the strongest peak. Disable Onset snap window when complete manual control is required. When you click on another tabsheet, all acoustic parameters are immediately updated for the corresponding band. In this way different onset times can be defined for each band. To permanently save the changes click Measured Response > Save Impulse response.

Manual truncation time

Similarly to the onset time you can decide where you want to truncate the impulse response by enabling the Manual truncation time option. Choose Measured Response > Manual truncation time (T shortcut). The mouse cursor becomes a *cross* symbol when hovering on the impulse response. Click anywhere on the impulse response to define a new truncation time for the current frequency band. If needed, zoom the area of interest by dragging a rectangle from top left to right bottom (to zoom out drag

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the opposite way). The red dotted line defining the truncation time moves now to the new point. When you click on another tabsheet, all acoustic parameters are immediately updated for the corresponding band. In this way different onset times can be defined for each band.

Restore automatic onset/truncation times

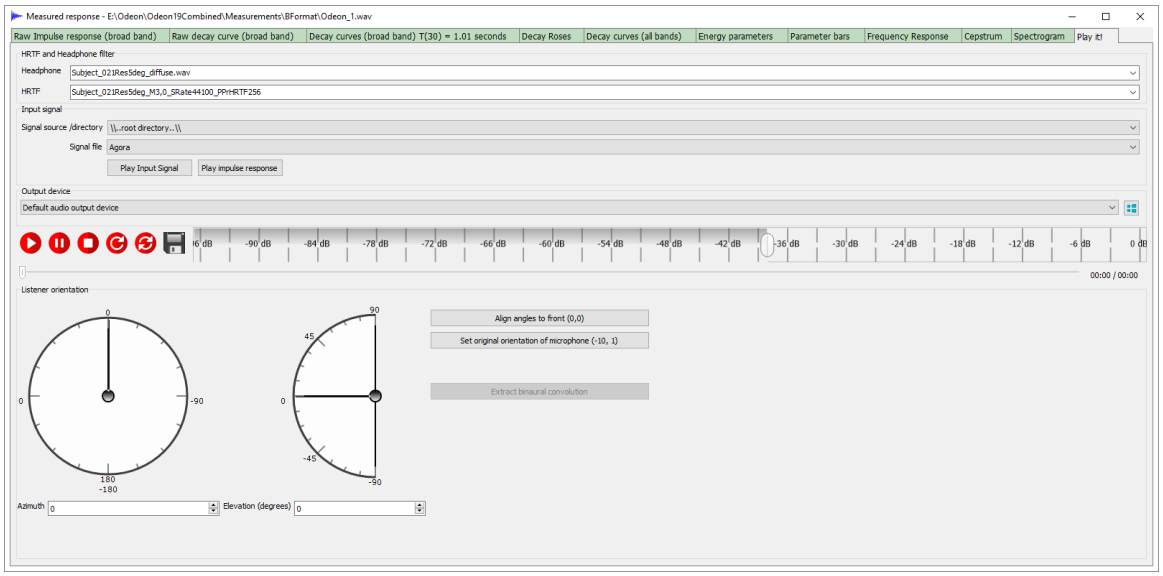
Choose the option Restore automatic truncation times or Restore automatic onset times and truncation times to restore the original settings by ODEON for the selected impulse response.

Save Impulse Response

When you make a manual change, the option Save impulse response becomes active so that any new onset or truncation times can be saved with the impulse response file. Click on the option, enter a new name, and click OK.

12.8 Making Auralisations with Impulse Responses

(Combined and Auditorium editions only)



A measured impulse response can be convolved with an anechoic signal in ODEON. After this operation, you can listen to how the anechoic signal would sound if it was played inside the measured room. The auralisation tool is available in the "Play it!" tab of the impulse response menu.

Note: ODEON also contains many tools for auralisation of simulated data. These are explained in Chapter 7.

Selection of an input anechoic signal

The anechoic signals should be placed in the chosen signal directory of ODEON (or in a sub-directory of it). The default directory is C:/OdeonXX[Edition]/WaveSignals, but you can change it in the Program Setup.

Convolution output

By default, the convolution output is stored in the Temp folder, meaning that it will be deleted when Windows is shut down. If you want to keep the file, you can specify another folder. The output file is automatically named after the impulse response file in use.

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Impulse response types and additional options

According to the nature of the loaded impulse response, additional options may be available.

Tip: For multi-channel signals, you can change the impulse response type by clicking on the contextual menu, Change Impulse Response Type. The proposed impulse response types will depend on the number of channels in the impulse response .wav file.

Mono impulse response

The anechoic signal is directly convolved with the impulse response. You can get a good idea about the room's effect, for instance in terms of reverberation. However, no localisation cue is included.

Binaural impulse response (2 channels)

If the impulse response was measured with a dummy head and contains two channels (one for each ear), you should choose the *Binaural type*. The convolution should be played via headphones and localisation cues will also be perceivable in the resulting auralisation.

If available, you can add a *headphone filter* in order to compensate for your headphones' frequency response. The chosen headphone filter should match the headphones you are using. You can read more about binaural settings in Section 7.3, and check **Appendix D** for the design of headphone inverse filters.

B-format impulse response (4 channels – 1st order)

ODEON can use B-format impulse responses to create binaural auralisations via headphones. B-format impulse responses include extended spatial information, which allows rotation of the listener. Therefore, when a B-format impulse response is loaded, you can adjust the listener orientation, both in terms of *azimuth* and *elevation*.

Binaural settings include the choice of a HRTF bank and a headphone filter. ODEON provides a few HRTF options, but you can also define your own HRTF bank. For more information on HRTFs, read **Appendix E**. The headphone filter should match the headphones you are using to listen to the auralisation, if available.

Quality of auralisation

The quality of the auralisation will greatly depend on the quality of the measured impulse response. This includes the equipment used to measure it, such as the microphone and the loudspeaker source. The reproduction setup, e.g., the headphones, will also affect the auralisation signal.

If you use the Odeon Omni source to measure a room's impulse response, ODEON can apply an inverse filter that will compensate for the frequency response of the source in your measurements. This improves the quality of the measured impulse response, and it results in more accurate auralisations, in particular with more low frequency content. The option is found in the measurement facility of ODEON.

Note: Odeon Omni is a portable omnidirectional source developed by ODEON A/S. You can read more about it on ODEON's website: https://odeon.dk/omni/

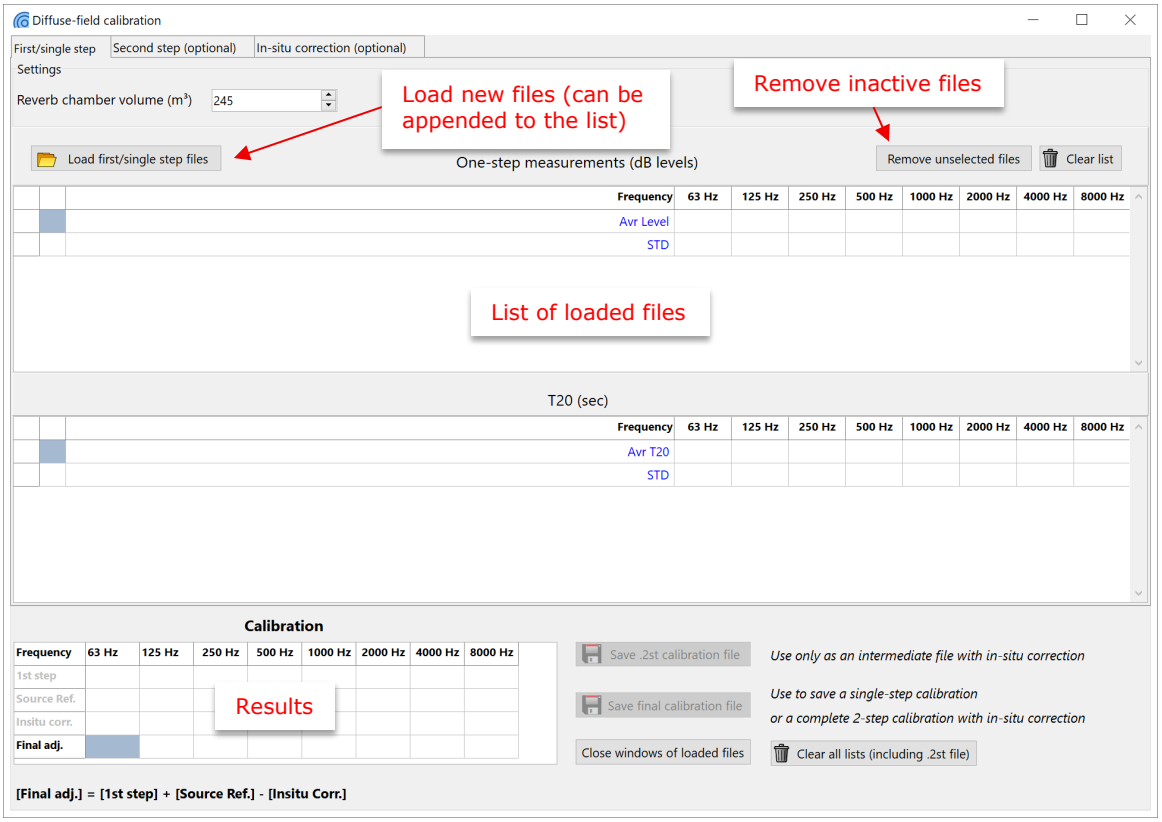
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12.9 Calibration of Measurements

So far, recording and processing of impulse responses have been described without taking calibration into account. In order to derive level parameters such as Sound Strength (G) and Speech Transmission Index (STI), the system set-up should be calibrated. Two calibration methods are available in ODEON that follow the ISO 3382-1 standard (ISO 3382-2, 2008): *Diffuse-field* and *Free-field* calibration. In the application note Calibration for impulse response measurements, you can read more about the calibration methods described in this section. The calibration interface has been re-designed in ODEON 19 to be more intuitive and user-friendly, offering greater flexibility in file management.

Diffuse-Field Calibration

This is the most common type of calibration and is recommended over the *Free-field* method due to its greater stability. A diffuse field calibration should be carried out in a room with long reverberation time and diffuse field, preferably a reverberation chamber. A group of source-receiver combinations is required. According to ISO 3382-2, at least two source positions and three receiver positions (6 source-receiver combinations), correspond to a moderate precision setting (*Engineering precision*). A minimum of 2 source-receiver combinations corresponds to the lowest acceptable precision (*Survey precision*), while at least 12 source-receiver combinations correspond to a top precision (*High precision*). The impulse response for each combination inside the reverberation chamber should be recorded and saved.
To access the calibration procedure interface, click Tools>Measurement Calibration>Diffuse filed/ Free field. The tool looks like below for the *Diffuse field* method.



The Measurement Calibration interface available in the Tools menu (*Diffuse-field* method).

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The interface supports two calibration procedures: *Single-step* and *Two-step*. While both methods produce the same results, the *Two-step* approach offers greater reliability, though it is somewhat more time-consuming.

Single-step procedure

A *Single-step* diffuse calibration corresponds to the standard procedure described in ISO 3382-1 (ISO 3382-2, 2008). The major requirement for this type is that all settings in the measuring equipment should stay fixed. This means that all devices (sound card, amplifier, microphone, cables) and gain settings (volume in the Operating System, amplifier volume) should remain unchanged when moving from the reverberation chamber to the actual room under measurement.

1. Perform a number of impulse response measurements at different locations of the source and the receiver in the reverberation chamber. Any positions are acceptable as long as the following are taken into account:
   - The height of the acoustic centre of the source should be 1.5 m above the floor.
   - The height of the microphone should be 1.2 m above the floor.
   - Different microphone positions shall be at least 2 m apart.
   - The distance of any microphone position to the nearest reflection surface – including the floor – shall be at least 1 m.
   - No microphone position should be very close to the source.
2. Record sufficient number of impulse responses according to the desired accuracy (from at least 2, for a *Survey precision*, to at least 12, for a *High precision*).
3. Click Tools>Measurement Calibration>Diffuse-field and select the First/Single step tab.
4. Insert the *volume* of the reverberation chamber in the *Settings* panel at the top.
5. Click Load first/single step files to load all impulse responses obtained in step 1 (use the Shift/Ctrl keys and left mouse button to select multiple files at once).
6. The calibration adjustments (from 63 Hz to 8000 Hz) appear at the bottom table once the files have been loaded. You can add more files/rows, deactivate or delete existing ones from the list.
7. You can either click Save final calibration file or close the window to save the file when prompted.
8. You will be prompted to choose whether you want the calibration file to be active or not.

Two-step procedure

A *Two-step* diffuse calibration keeps all important aspects of the standard *Single-step* diffuse calibration, but it removes the requirement of having a fixed measuring system when moving from the reverberation chamber to the measurement in-situ. In the paper "Applying In-situ Recalibration for Sound Strength Measurements in Auditoria" (C. L. Christensen, 2015) the underlying theory of this method is analyzed. The basic workflow of the *Single-step* calibration remains the same, but an extra part is added at the end, which ensures that the acoustic power of the source has been recorded and tracked from the diffuse chamber to the actual measurement room. This final part makes it easy to recover any changes in the measuring equipment that affected the output of the source and occurred between the reverberation chamber and the measurement in-situ. Apart from the series of impulse responses recorded normally for the diffuse calibration method, one more impulse response measurement has to be loaded when the microphone is placed at a known distance in front of a known direction from the source. This happens still inside the reverberation chamber. In this way, ODEON will try to isolate the direct sound from the source at this exact position. Later on, the measurement can be repeated *in-situ*. If there is any change in the equipment that affects the power of the source, it will be reported as a correction factor. Since the direct sound – or at least a big part of it - has to be isolated from subsequent reflections the heights of the source and microphone should be at least 1 m. Moreover, the distance between source and receiver should be less or equal to 1 m.

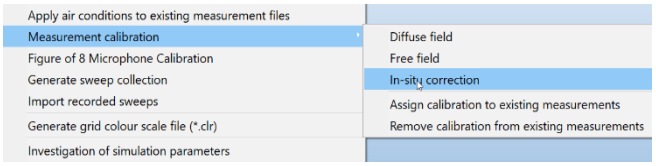
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To perform a *Two-step* calibration, first follow steps 1–5 of the *Single-step* calibration procedure. Then add the following steps:

1. Select the Second step (optional) tab in the same interface.
2. Click Load second step (source ref. files) to load one or more measurements at a fixed location in front of the source. Use the Shift/Ctrl keys and left mouse button for selecting multiple ones.
3. The corresponding impulse response windows will open and the source reference values will be added at the bottom table of the calibration window.
4. Click Save .2st calibration file to save an *intermediate* calibration file that can be finalized when at in-situ correction file (measured in the actual room) has been loaded.

In-situ correction

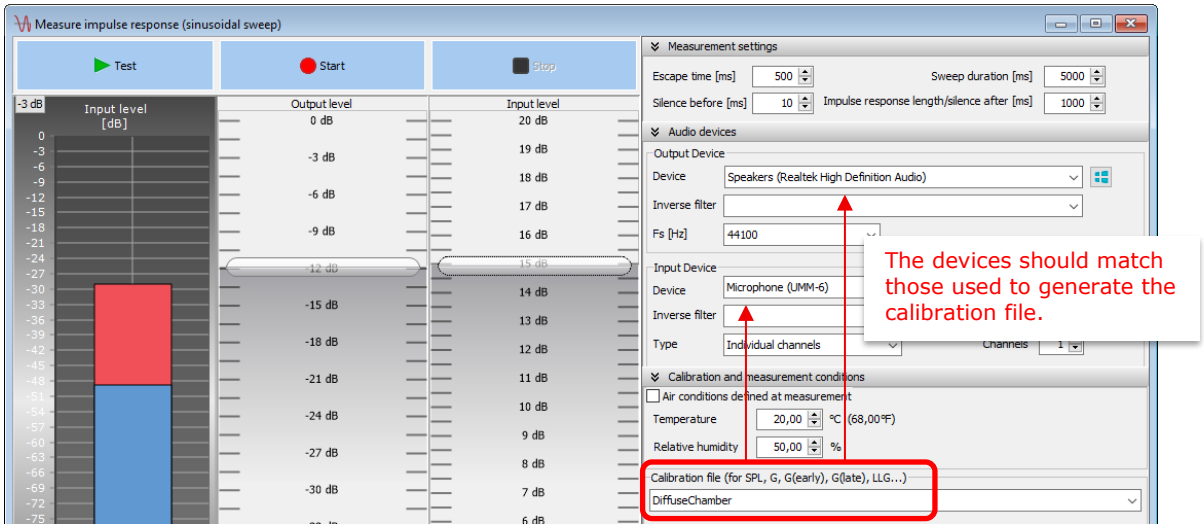
The *intermediate* calibration file can now be used to make an in-situ correction in the room under measurement, to derive the final calibration file.



Make one more measurement in-situ with the microphone placed at the same position and distance as with the source reference measurement.

1. Click Tools>Measurement Calibration> In-situ correction.
2. ODEON asks you to load the .2st calibration file on which the complete calibration will be applied. After loading the file, the *1st Step* and *Source Ref.* values appear in the Calibration table at the bottom of the interface. Note that these values are greyed out, indicating they are not yet in use until the in-situ correction is applied. Likewise, both **Save** buttons remain disabled.
3. Load one or more impulse responses recorded *in-situ* at a fixed position and distance in front of the source. The in-situ correction values complete the Calibration table and now all rows and **Save** buttons become active.
4. You can either click Save final calibration file or close the window to save the file when prompted.
5. After that choose whether you want the calibration file to be active or not.

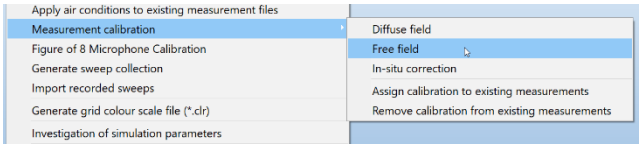
Remember: After the calibration procedure is finished you are asked if you want to set the saved calibration file as *active*. The active file will be displayed in the Measure impulse response (sinusoidal sweep) window and will be applied in any subsequent measurement, unless changed in the drop-down menu. The calibration file is linked to a specific audio setup; therefore, the *Output* and *Input* devices should match those used to generate the calibration file. If not, a warning message will be displayed.



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Free-Field Calibration

Ideally this should be carried out in an *anechoic room*, but in many cases, it can be carried out in a relatively dry room. The receiver should be placed close to the source and the impulse responses should be recorded.



ODEON will try to capture the very early part of the response, corresponding to the direct sound. According to the distance between the source and the receiver and their heights from the floor, the arrival time of the 1st reflection is calculated so that the impulse response is truncated at this place. Ideally only the energy of the direct sound should remain after the truncation. Unfortunately, the truncation is approximate at low frequencies because the direct sound and the subsequent reflections overlap, due to the long wavelengths of the sound waves and the presence of phase shifts.

It is recommended that more than six source-receiver combinations should be used for the *free field* calibration since it is very likely that the source does not produce a perfect omni directional pattern, but a pattern with side lobes. This means that in contrast to the *diffuse field* calibration, the free-field calibration is very sensitive to receiver positions around the source. Similarly to the diffuse calibration, you should select and load all impulse responses obtained for the same calibration at once, so that ODEON will calibrate the level according to the average of the values.

Single step

A Single step *Free-field* calibration corresponds to the standard procedure described in ISO 3382-1 (ISO 3382-2, 2008). The major requirement for this type is that any external level adjustment not adjusted inside ODEON, is set to the same level during the room measurement as during the calibration. This includes levels set for play back level (if set to 100% it's easy to remember and set), recording level (if set to 100% it's easy to remember and set) and microphone boost set inside the Operating System as well as gain factors set on external devices used in the measurements. The equipment itself (sound card, amplifier, microphone, cables) should also remain unchanged. For a thorough walkthrough of the calibration method, read the application note Calibration for impulse response measurements.

1. You need to perform impulse response measurements over a full circle at a fixed radius, covering between 15 and 30 positions (24° to 12°). The following requirements must be respected:
   - The distance (radius) between the source and the microphone (receiver) should be at least 2 m.
   - Both the source and the microphone are positioned no closer than 1 m from any wall.
2. Click Tools>Measurement Calibration>Free-Field and select the First/Single step tab.
3. Enter the *Source Height*, *Receiver Height* and *Source-Receiver distance* at the Settings panel.
4. Click Load first/single step files to load all impulse responses obtained in step 1 (use the Shift/Ctrl keys and left mouse button to select multiple at once). The adjustment values (from 63 Hz to 8000 Hz) will be displayed in the Calibration table at the bottom of the interface.
5. You can either click Save final calibration file or close the window to save the file when prompted.
6. Choose whether you want the calibration file to be active or not.

Two-step

A *Two-step* diffuse calibration keeps all important aspects of the standard *Single-step* free-field calibration, but it removes the requirement of having a fixed measuring system when moving from the anechoic chamber to the measurement *in-situ*. As in the Two-step *Diffuse-field* calibration method, steps 1-4 of the *Single-step* procedure stay the same, but a *Second step* is added to register the acoustic power of the source at the time of calibration – at a fixed distance and position in front of the source. This extra part makes it easy to recover any changes in the measuring equipment that

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affected the output of the source and occurred between the *anechoic chamber* and the measurement *in-situ*.
The second step should be recorded also in the *Anechoic Chamber*. ODEON will try to isolate the direct sound from the source at this exact position. Since the direct sound – or at least a big part of it – has to be isolated from subsequent reflections the following two restrictions need to be respected:

- Heights of the source and microphone should be at least 1 m.
- The distance between source and receiver should be less or equal to 1 m.

To perform a Two-step calibration, first follow steps 1–4 of the Single-step calibration procedure. Then, repeat steps 1–4 from the *Two-step* calibration of the *Diffuse-field* method to add the source reference and save the *intermediate* .2st calibration file.

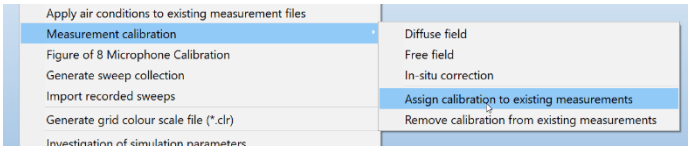
In situ correction

As with the *Two-step* procedure above, the steps of the *In-situ* correction are identical to those of the *Diffuse-field* method.

Remember: After the calibration procedure is finished you are asked if you want to set the saved calibration file as *active*. The active file will be displayed in the Measure impulse response (sinusoidal sweep) window and will be applied in any subsequent measurement, unless changed in the drop-down menu.

Assign Calibration to existing measurements

In many cases it is more convenient to perform all impulse response recordings first and apply calibration afterwards. This means that impulse responses can be obtained both in the reverberation or anechoic chamber and in-situ at once and later on be used for deriving the calibration files and the final calibrated measurement files.
Once the calibration files have been derived with one of the methods described previously, click Tools>Measurement Calibration>Assign calibration to existing measurements.



ODEON will ask to select an existing calibration file. Now the in-situ recordings can be loaded. The recording steps that need to be followed for a post-measurement calibration can be summarized as follows:

1. Perform and store as many impulse response recordings as required for a diffuse or a free-field calibration inside an anechoic or reverberation chamber respectively.
2. If a *two-step* method is chosen, record an extra set of impulse responses at a specific distance and location from the source. Write down the distance and the exact location of the microphone relative to the source. If possible, take more than one measurement, even though the position is the same. This will help to smooth out any random errors.
3. Enter the actual room under measurement (in-situ). If a *two-step* method is chosen, repeat the set of measurements for the same distance – location. If any changes in the gains of the measuring equipment have been made, they will be corrected. If nothing is changed there will be just a null correction.
4. Record and store all impulse responses desired in the room under measurement (in-situ).

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Figure 8 calibration

In ODEON 14, one more calibration method was added: the figure 8 microphone calibration. This is necessary for measuring the Early Lateral Energy parameter, which expresses the fraction of energy J_{LF} arriving from lateral directions within the first 80 ms (ISO 3382-1, 2009):

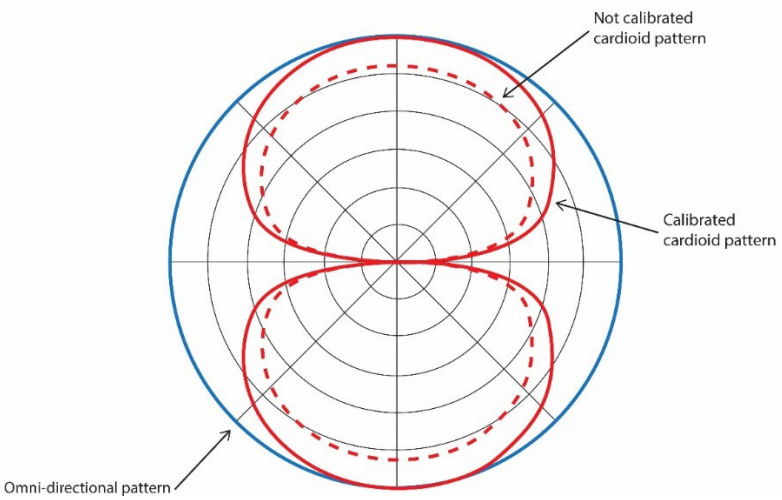
$$J_{LF} = \frac{\int_{0,005}^{0,080} p_L^2(t)dt}{\int_{0}^{0,080} p^2(t)dt}$$

In this equation:

$P_L(t)$ is the instantaneous sound pressure of the impulse response in the room, measured with a figure-8 pattern microphone.

$P(t)$ is the instantaneous sound pressure of the impulse response measured at the measurement point with an omni-directional microphone.

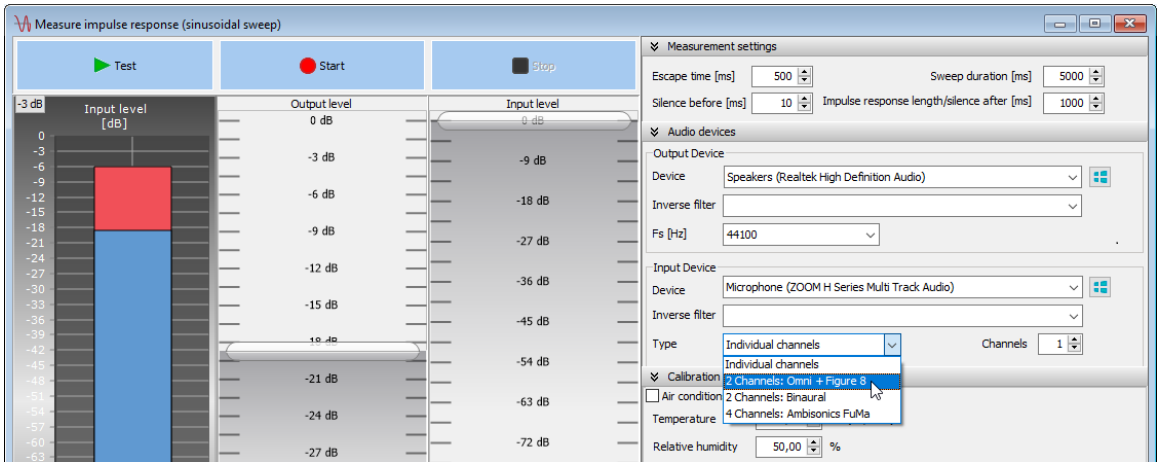
From the foregoing equation it is shown that for such a measurement a microphone with two channels is needed: An omni and a figure-8 channel. The sensitivities of these microphones should be adjusted so that the peaks of the two channels coincide.



For measurement of the J_{LF} parameter the sensitivities of an omni and a figure 8 channel should be aligned, i.e. the maximum sensitivity value of the figure 8 channel should be equal to the sensitivity value of the omni directional channel.

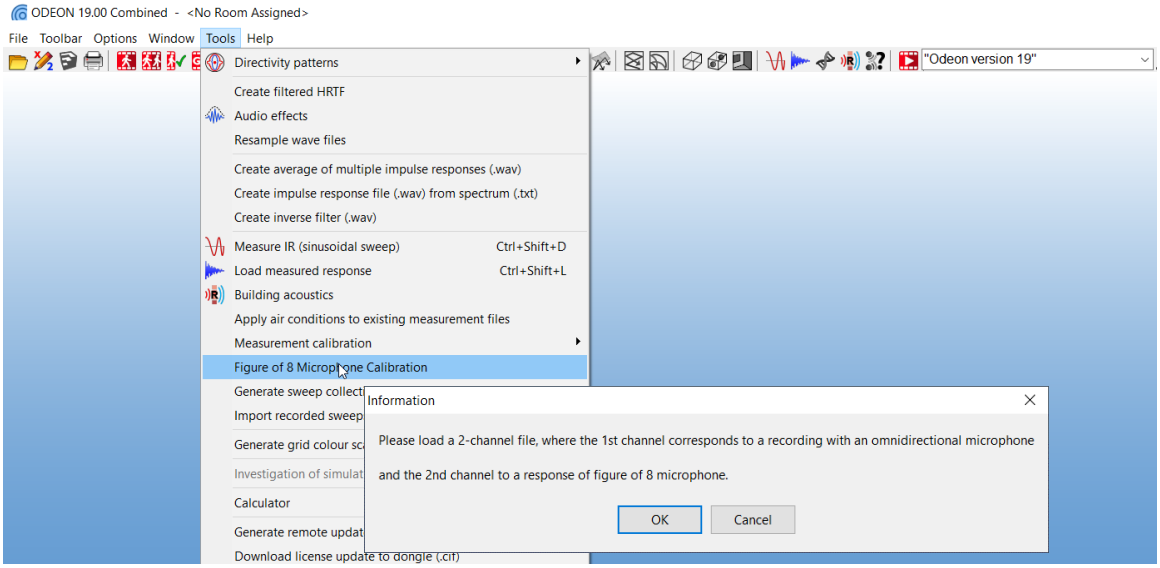
An impulse response in a fairly damped room needs to be captured with both the omni and the figure 8 channels being active. Please make sure that 2 Channels: Omni+Figure 8 is the active input device type in Measure Impulse Response>Type.

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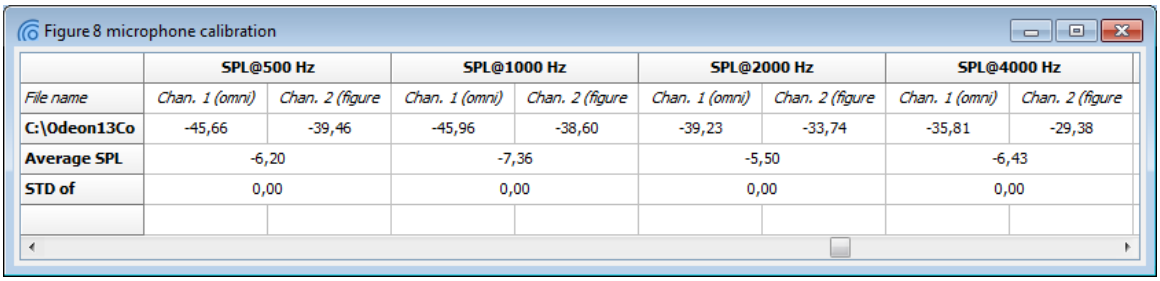


ODEON will try to separate the direct sound arriving at the microphone from subsequent reflections.

1. Click Tools>Measurements Calibrations>Figure of 8 Microphone Calibration.



2. ODEON asks for a 2-channel impulse response.
3. Load one or more impulse responses recorded with the 2-channel microphone.
4. ODEON calculates the difference between the omni and the figure-8 channel. This difference is then used to equalize the peaks of the corresponding sensitivities.



	SPL@500 Hz		SPL@1000 Hz		SPL@2000 Hz		SPL@4000 Hz	
File name	*Chan. 1 (omni)*	*Chan. 2 (figure*	*Chan. 1 (omni)*	*Chan. 2 (figure*	*Chan. 1 (omni)*	*Chan. 2 (figure*	*Chan. 1 (omni)*	*Chan. 2 (figure*
C:\Odeon13Co	-45,66	-39,46	-45,96	-38,60	-39,23	-33,74	-35,81	-29,38
Average SPL	-6,20		-7,36		-5,50		-6,43	
STD of	0,00		0,00		0,00		0,00	

5. Save the calibration file.
6. Choose whether you want the calibration file to be active or not.

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12.10 Examples of Impulse Responses – Warnings

A reliable measurement result relies on a healthy impulse response. Although it is difficult to give a general definition on what a "healthy" impulse response is, here are some guidelines that may help in obtaining acceptable results:

1) Sufficient signal noise ratio (at least in the octave bands of interest).

Tip: If your equipment does not allow sufficient increase of gain for obtaining a good signal to noise ratio, set the sweep length as long as possible (eg. 60 sec). Every doubling of the sweep length results to a suppression of the noise floor by 3 dB. As an example, increasing a sweep signal from 2 sec to 64 sec will result to a 15 dB gain in the signal to noise ratio.

2) A noise floor as flat as possible (if the noise floor is included in the impulse response) at the end of the response is a good indication that the impulse response is not polluted by impulsive noise.
3) No presence of quantization artefacts due to poor recording resolution (input level at recording of the impulse response should be high enough).
4) Presence of spikes/hills in the impulse response could indicate presence of impulsive noise during the measurement no matter if the impulse response was recorded directly (using external impulses) or obtained using the sweep method implemented in ODEON. If in doubt, it is a good idea to make an extra measurement while still in the field to see if it is consistent. Try to make a measurement with a much longer sweep (if using the sweep method). Normally such errors will issue a WARNING message in the title bar of the measurement window stating the value of XI (non-linearity parameter) is too high.

Remember: ODEON helps you making a high-quality measurement by displaying WARNING messages in the title bar of the measurement window. Moreover, when the Signal-to-Noise ratio is not sufficient, ODEON will display asterisks "*" instead of values for the various acoustic parameters.

In the Errors subfolder inside the Measurement folder of your ODEON installation there are examples of bad impulse responses, due to distortion, low Signal-to-Noise ratio and electromagnetic feedback. While Signal-to-Noise ratio or electromagnetic feedback may be something easy to track in the measurement, distortion does not provide clear signs and might let us accept an overall pure-quality impulse response. Examples of good and bad impulse responses are given below.

Warning messages

Depending on the quality of the measurement, ODEON may display a warning message in the title bar of the measurement window informing of a possible concern with the measurement, prioritized in the order listed below.

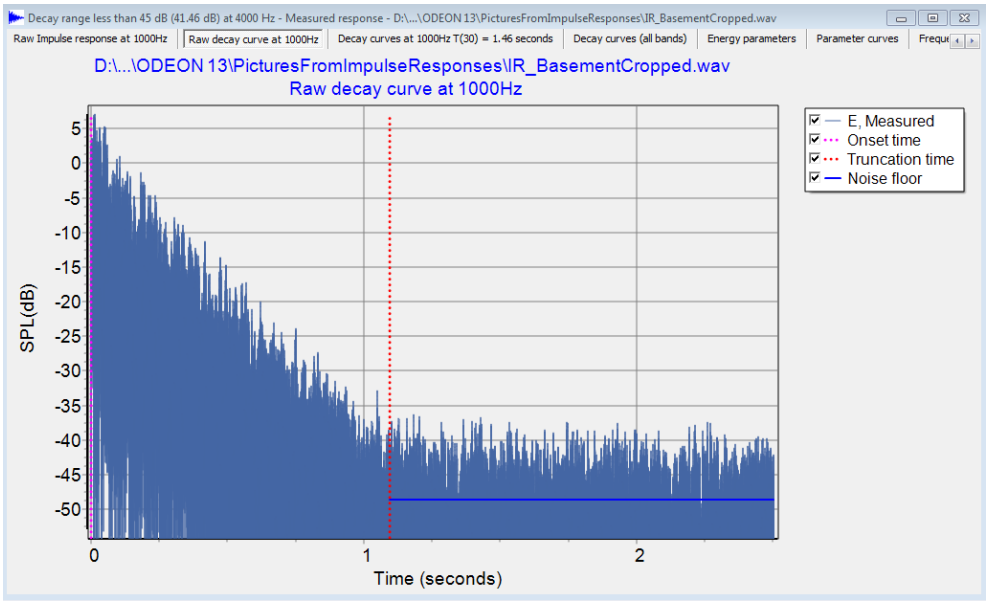
- Significant distortion products.
- Issues with the impulse/squared impulse responses (i.e. suspicious bumps).
- Problems with estimating onset and truncation.
- Unable to derive some room acoustic parameters

In these cases, it is recommended to perform a visual inspection of the impulse response and check that - remember that there is more than one octave band to look at. The warning messages concern frequencies between 125 and 4000 Hz, which are the most important according to the ISO standard 3382 (ISO 3382-1, 2009).

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Impulse response with well-defined noise floor

The following figure displays the raw decay curve for a typical impulse response filtered at the octave band of 1000 Hz. The particular impulse response has a well-detected noise floor (solid blue line) with well-defined onset (pink line) and truncation times (red line). In the ODEON measuring system, the noise floor is automatically calculated individually for each octave band. Subsequently a truncation time is automatically derived. If another truncation time is needed, you can do so manually following the instructions in Section 12.9.

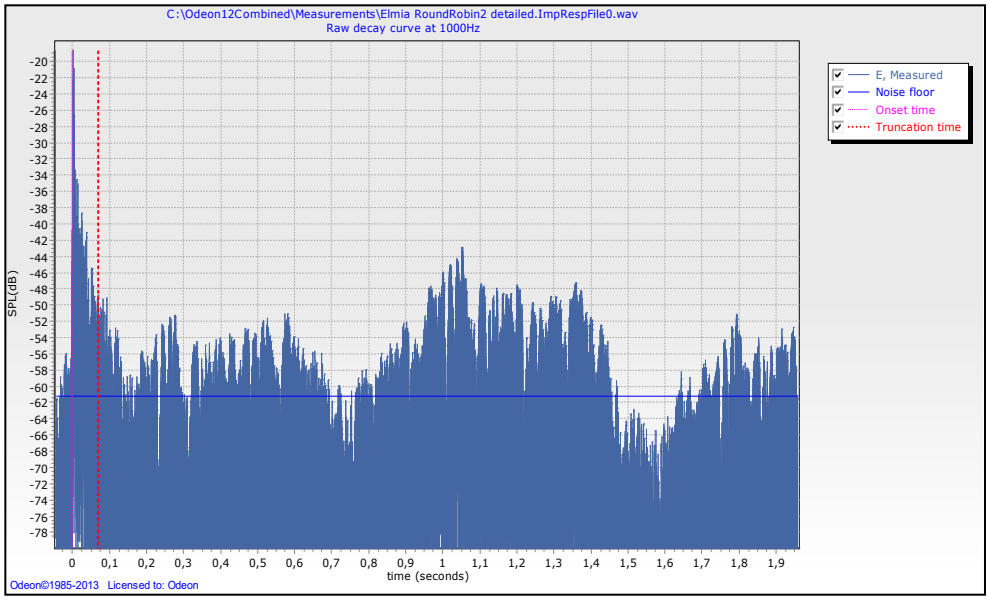


A typical impulse response with a well-defined “healthy” noise floor, that is easy to be detected by ODEON.

Impulse response with fluctuating noise floor

The tail of the impulse response in the following figure is polluted by a high degree of non-flat noise floor, full of dips and notches. This can be an indication of presence of strong background noise during the measurement and the Signal-to-Noise ratio is insufficient for the calculation of all room acoustic parameters. In these cases, ODEON typically displays a fluctuating noise floor with a dashed blue line. However, in this particular case this prolonged fluctuating noise floor cannot be detected as fluctuating and ODEON places a normal blue line instead. In such a case, it is wise to visually inspect the fluctuating envelope of the noise floor and repeat the measurement under less noisy conditions.

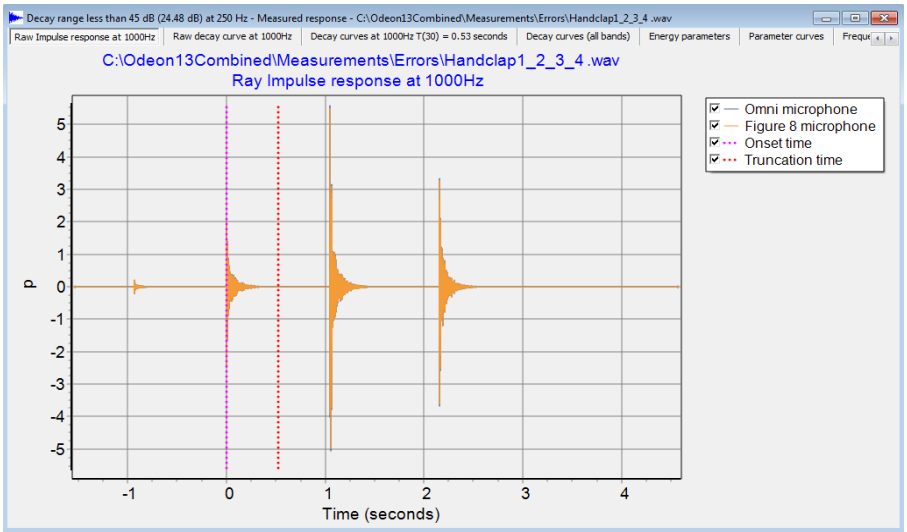
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An impulse response with highly fluctuating noise floor.

Series of impulse responses

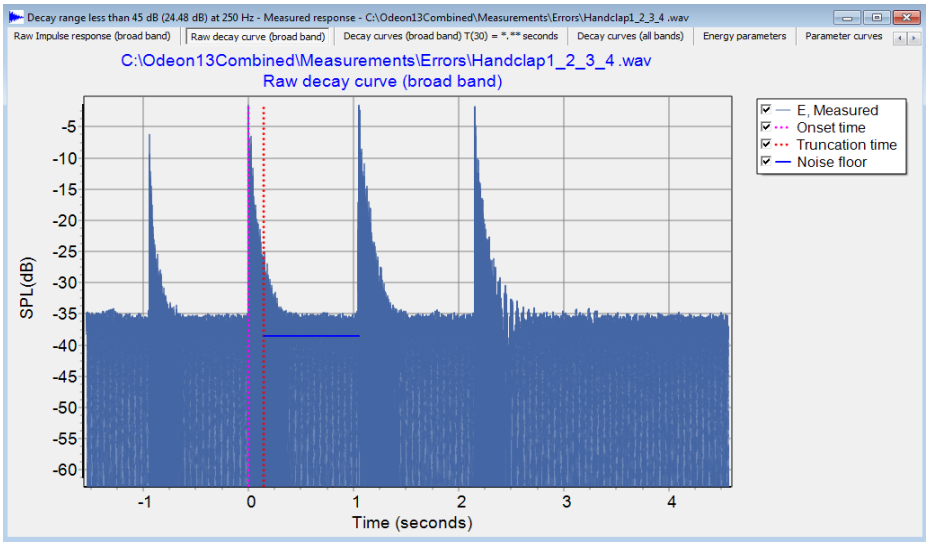
The next two figures show an impulse response recording containing 4 hand claps in a row. Only one of the impulse responses has to be processed. ODEON detects the one that has the highest peak in the broadband version – i.e. the 2nd one. The beginning of the 3rd impulse response defines the end of the noise floor for the 2nd impulse response, so that the truncation point is correctly placed with respect to the noise floor associated with the 2nd impulse response. If you wish to process another impulse response you should crop the desired part of the recording and save it as a new file (zoom the relevant part – then save it using the c-shortcut). Once the file has been saved it is automatically opened in the Measured Response window. You can also redefine the onset and truncation times, as described in Chapter 0 and save the impulse response with a new name.



A series of hand-clap recordings in a room. The 1000 Hz octave band is shown. Hand–claps are an effective way to obtain sketch impulse responses in rooms.

In the next figure the broadband signal is shown. Onset and truncation times are derived automatically but the Signal-to-Noise ratio is very poor for the selected impulse response and its length is too short, so that a stable noise floor cannot be derived. Therefore, some acoustic parameters cannot be calculated in this case.

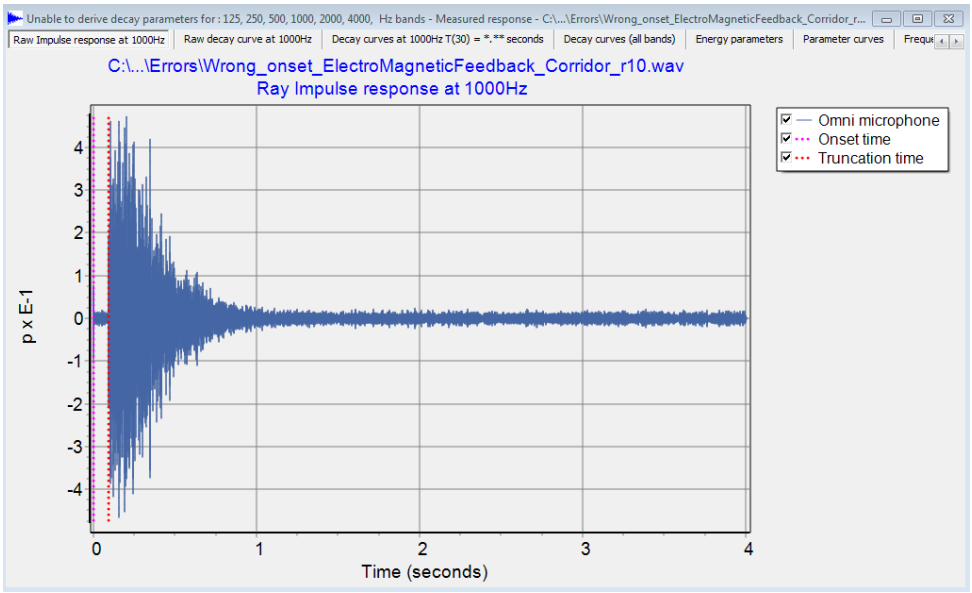
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The same hand-clap recordings as in previous figure but in dB, so that the dynamic range is more visible. Broadband signal is shown.

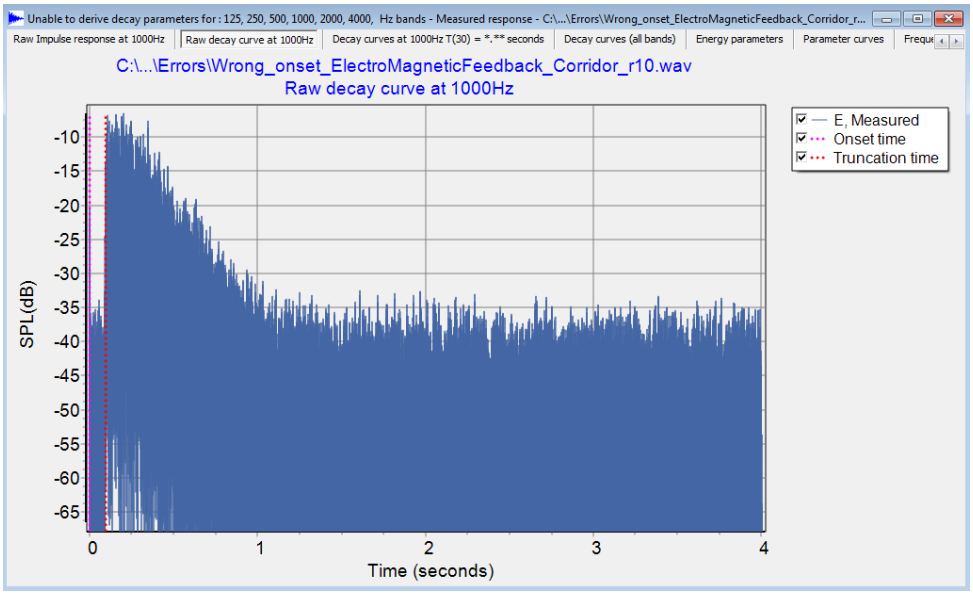
Impulse response with electromagnetic feedback

When long cables are used in a measurement for the microphone as well as for the loudspeaker and the cables lie close to each other and parallel for some distance, this can lead to electromagnetic feedback, resulting in an early peak with virtually no delay, arriving some time before the start of the impulse response is actually detected by the microphone. This peak is undesirable and should be removed. Changing the noise floor window length can help in placing the truncation time at a correct place, but the onset time will be still placed wrongly at the peak of the magnetic feedback. The best solution is to zoom the healthy part of the impulse response then save this cropped version using the c-shortcut. Manual setting of onset time is also possible, according to Chapter 0. It is of course better to avoid long parallel cables in the first place – if you are still in the field then by all means repeat the measurement.



Electromagnetic feedback in an impulse response recording.

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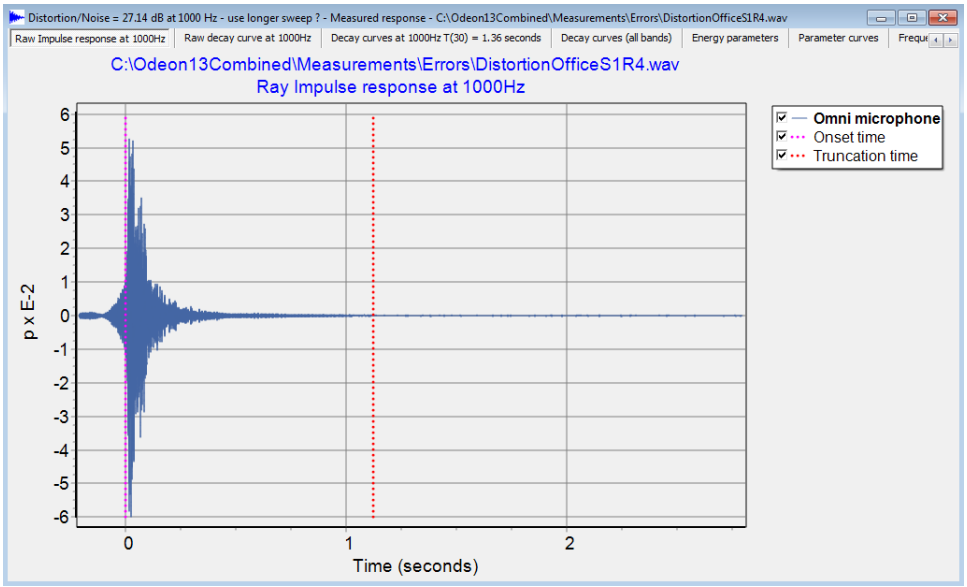
Electromagnetic feedback in an impulse response recording. Same file as in previous figure but in dB for better visualizing the dynamic range.

Impulse response with harmonic distortion

Harmonic distortion can occur at excessive high gains in some loudspeakers. It can be a significant problem, not easy to track and it can pollute the entire impulse response. However, part of a distortion is visible at the beginning of the impulse response as a build-up – before arrival of direct sound. Always inspect an impulse response for distortion and repeat the measurement if in doubt of the quality. The following figures give examples of harmonic distortion.

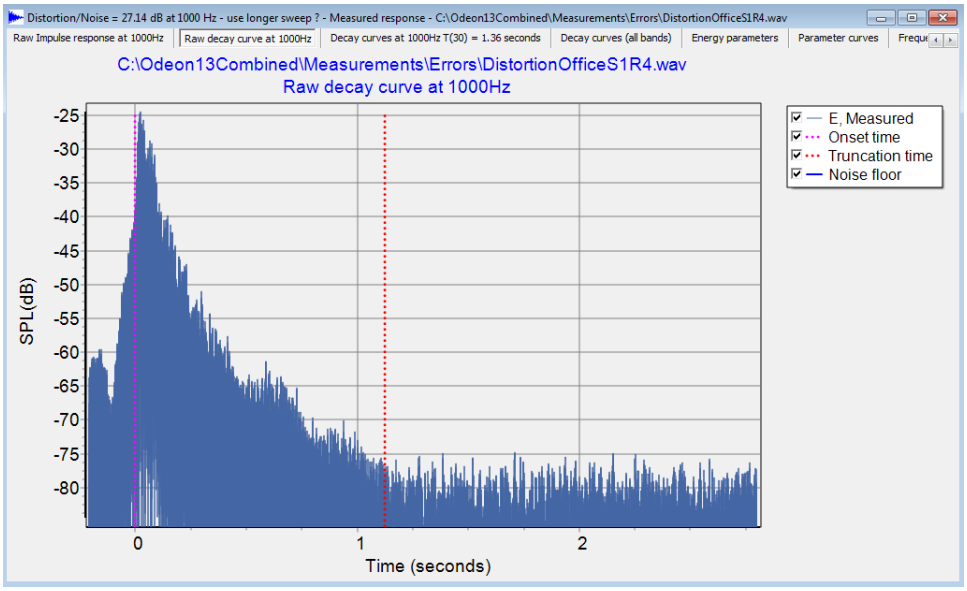
The following common enhancements in sound cards can lead to distortion products. Be sure to deactivate them:

- Echo cancellation.
- Automatic gain control.



Harmonic distortion visible as a build-up before the beginning of an impulse response. Pressure domain.

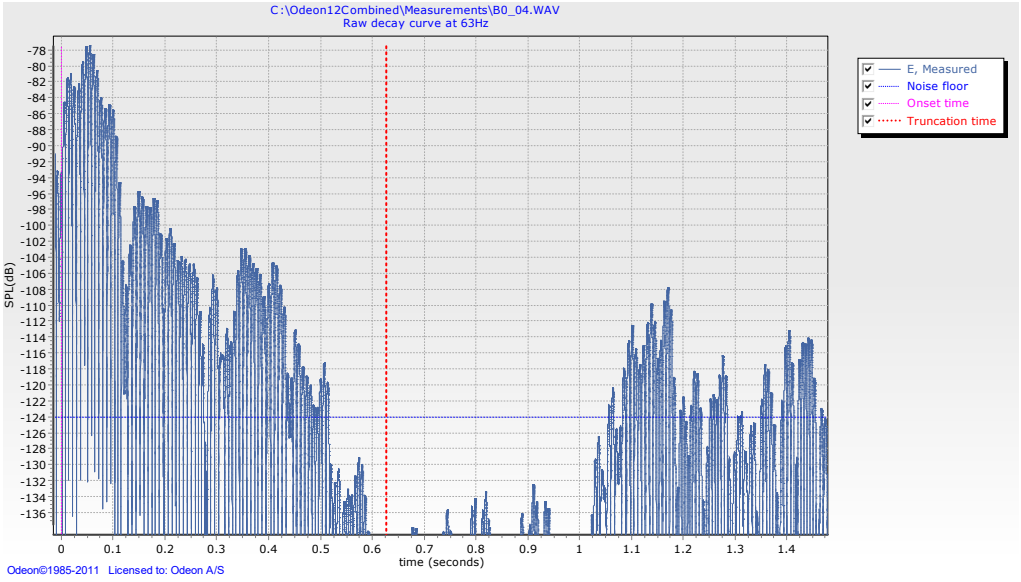
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The impulse response shown on the previous figure but in dB. It is clearly seen that the harmonic distortion leads to a blurred onset of the impulse response.

Impulse response with distortion at the end

Distortion at the end, which appears as a "notch" of noise may have been caused due to presence of spikes in a measurement with the sweep method.



Impulse response with a prominent notch at the end. Such a type of hill indicates that strong spikes were present during the measurement. When using the Sweep method, spikes in the recording are converted to hills after the deconvolution.

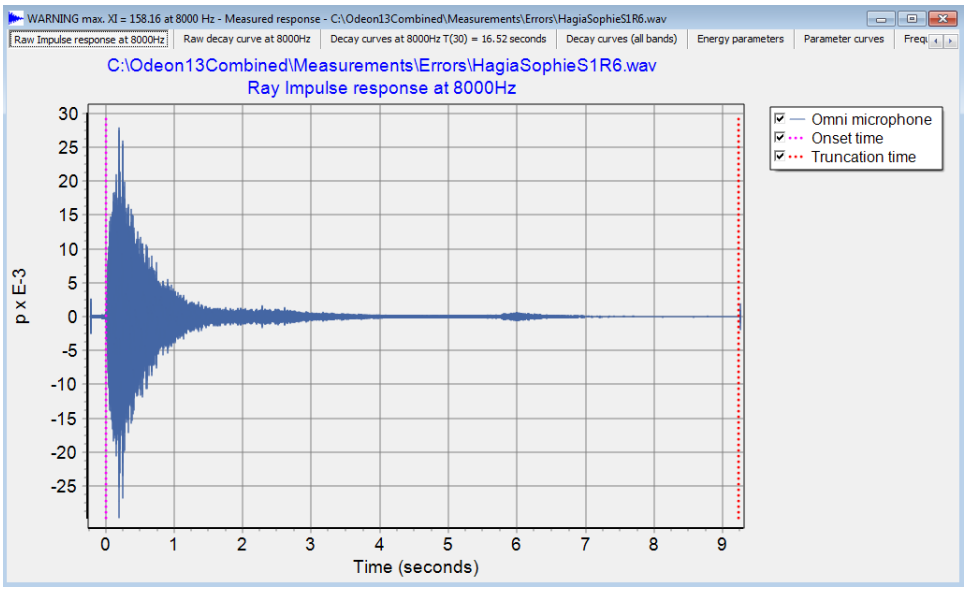
High Non-linearity in the decay

When the energy decay is non-linear, calculation of reverberation time may be questionable, as by definition reverberation time is calculated for an exponential energy decay – translated to a linear decay in a dB scale. Not only reverberation time but a group of many other parameters require an exponential energy decay, as described in the ISO standard 3382 (ISO 3382-1, 2009). The XI parameter is used to quantify the degree of non-linearity in an impulse response. Values greater than 10 ‰ indicate a questionable non-linearity in the decay. This may indicate that there is something wrong with the captured impulse response (e.g. sudden noise during the measurement)

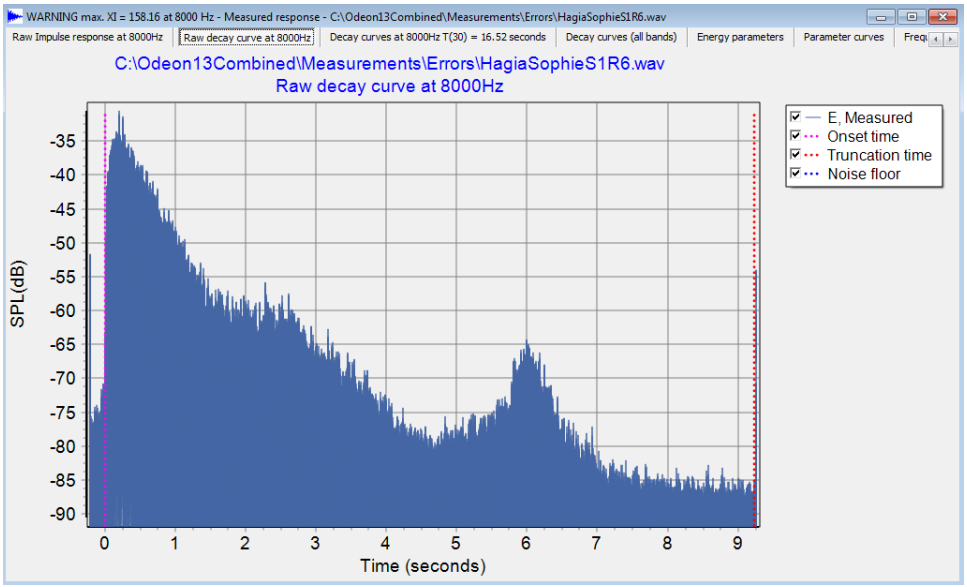
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or indeed that the behaviour of the room is non-linear. As an example, assume a rectangular room with uniform low absorption on all surfaces except from the ceiling – which is highly absorptive. The resulting decay curve experiences a "knee" point that changes the slope and leads to a double curved decay, with a high XI value.

In the figure below, ODEON has placed the following warning message in the title bar: "WARNING max. XI = 158.16 at 8000 Hz" (the XI value shown is per-mille).



Impulse response with decay of high non-linearity.



Impulse response with decay of high non-linearity. Same recording as in previous figure but in dB scale, where a normal exponential decay should look like a straight line.

Similar messages are displayed for other frequencies. If you are suspicious about the quality of measurement and if you believe the high value of XI is due to the recording, repeat the measurement. Check if the errors (like high XI) are reproducible. In addition, check if there is any sign of harmonic distortion, as described previously.

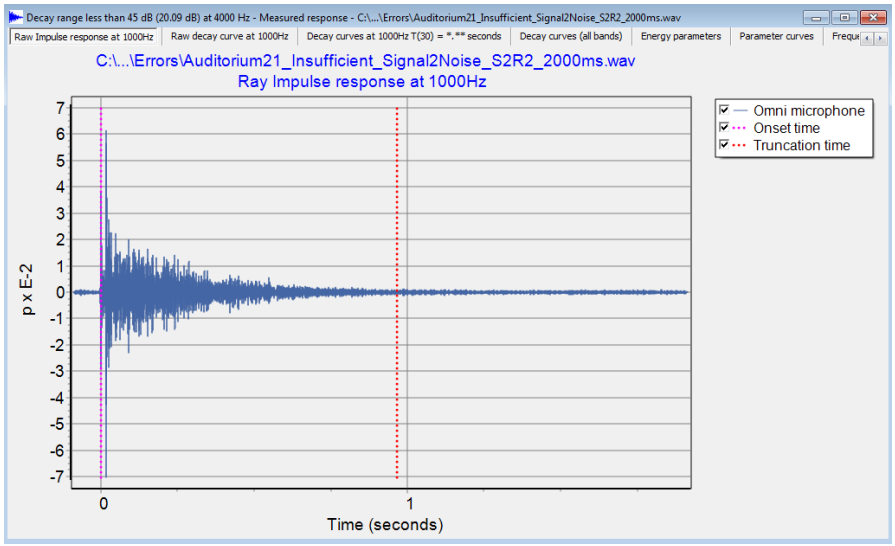
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Insufficient Signal-to-Noise ratio

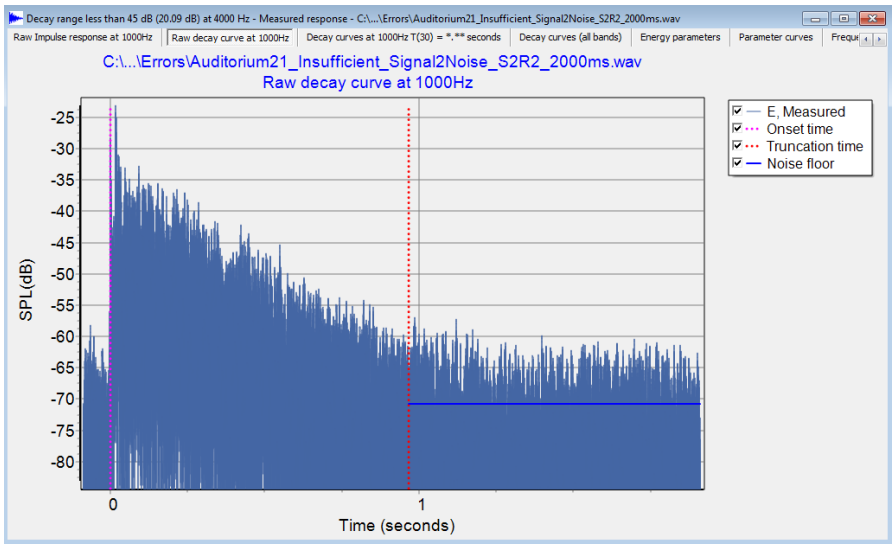
In order to derive T_{30} at least 35 dB of valid decay must be present for each octave. Reasons for not obtaining a valid decay curve might be:

- The captured impulse response may be too short because the impulse response length used during the measurement was too short – in this case, make a new measurement with a longer impulse response length.
- The Signal-to-Noise ratio was too poor, i.e. the decay disappears into the noise floor – in this case increase the level of the loudspeaker (at the same time making sure your signal does not clip) and/or extend the sweep length.

In the following impulse response (shown both in pressure and dB units) the Signal-to-Noise ratio is not sufficient. According to the ISO standard 3382, the measured impulse response should be valid at least an additional 10 dB below the lowest decay level required to derive the decay parameter. For example, for the T_{30} parameter, the decay range should reach 10 dB below -35 dB, resulting in a total decay range of 45 dB. Results may be fairly reliable as ODEON tries to compensate for the noise floor. In the following example the decay range is less than 45 dB at 1000 Hz and therefore T_{30} cannot be reliably derived.



Impulse response with insufficient Signal-to-Noise ratio.



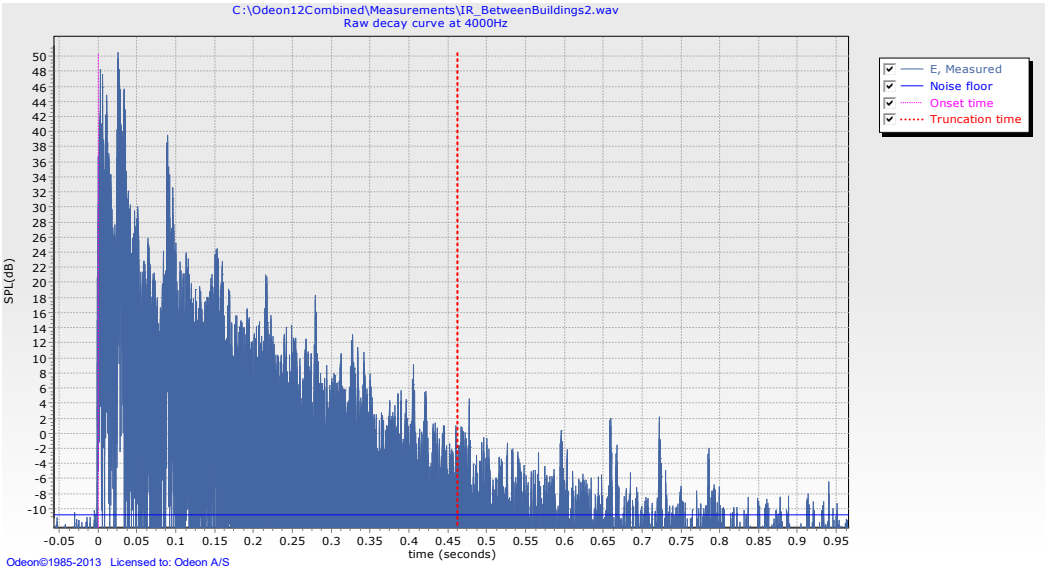
Impulse response with insufficient Signal-to-Noise ratio. Same recording as in previous figure but in dB.

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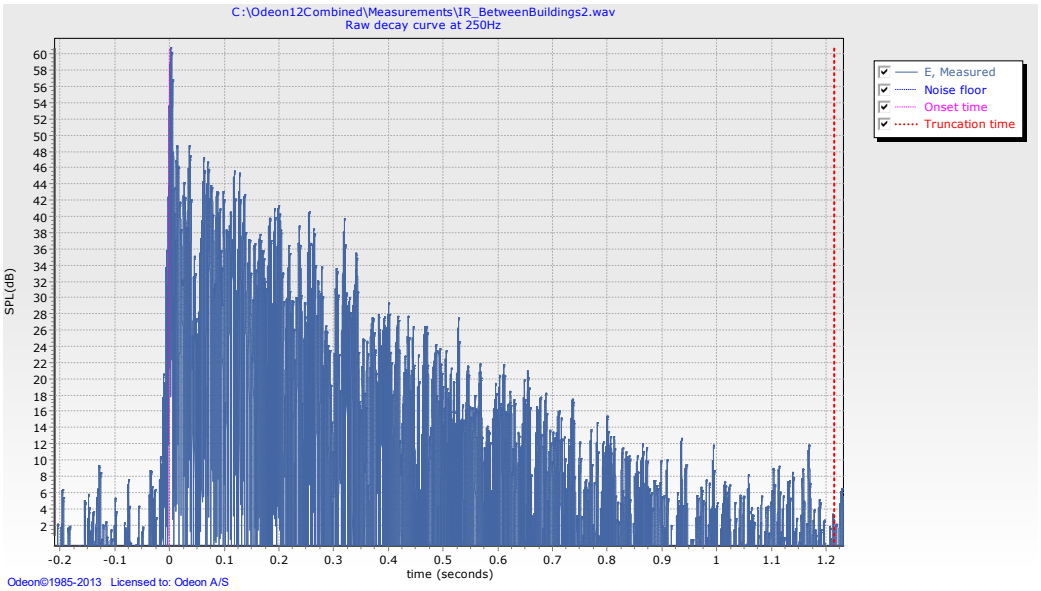
Tip: Every doubling of the sweep length results to a suppression of the noise floor by 3 dB. As an example, increasing a sweep signal from 2 sec to 64 sec will result to a 15 dB gain in the signal to noise ratio.

Impulse response between buildings

This is an example of measurement outdoors, between several buildings. In this case distant strong spikes at high frequencies indicate the presence of prominent echoes between the buildings. At low frequencies the effect is less prominent. In addition, the reverberation time is much longer at low frequencies.



Impulse response with prominent spikes at regular distances that indicate the presence of (flutter) echoes in the field between the buildings. The frequency is 4000 Hz.



At 250 Hz the echoes are less distinct, but the reverberation time is longer.

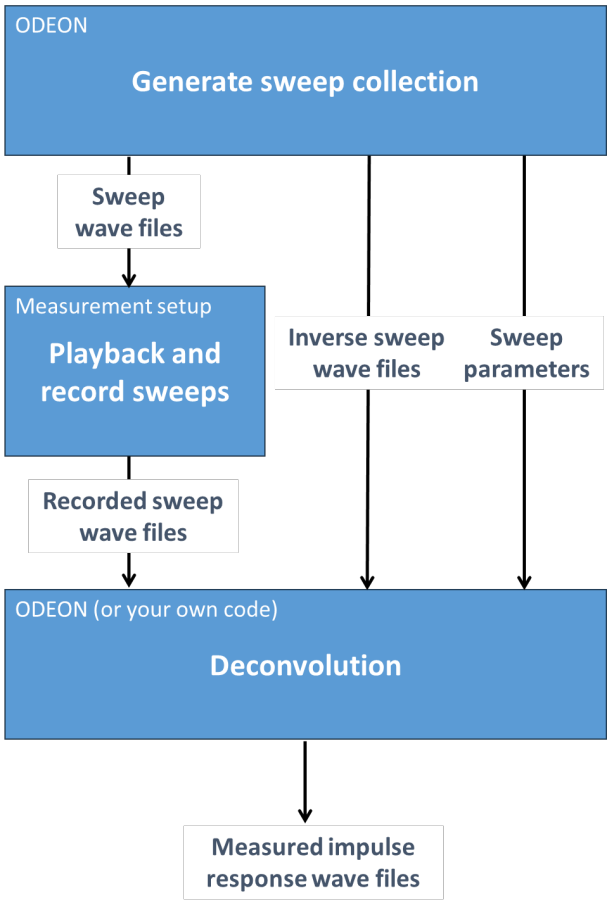
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12.11 Open-loop sweep measurements

In some cases, you might need to perform measurements without the ODEON software. Typical cases are listed here:

- You do not have access to ODEON during the measurements.
- The measurement system is incompatible with your PC and/or ODEON (e.g. audio device not supported by the Windows Driver Model).
- You are trying to perform ambisonics measurements but your equipment only outputs A-format files.

ODEON enables you to export a series of sweeps, as well as their respective inverse sweeps, which you can play and record on any measurement system. The recorded sweeps can then either be deconvolved using the corresponding inverse sweeps, or reimported into ODEON.

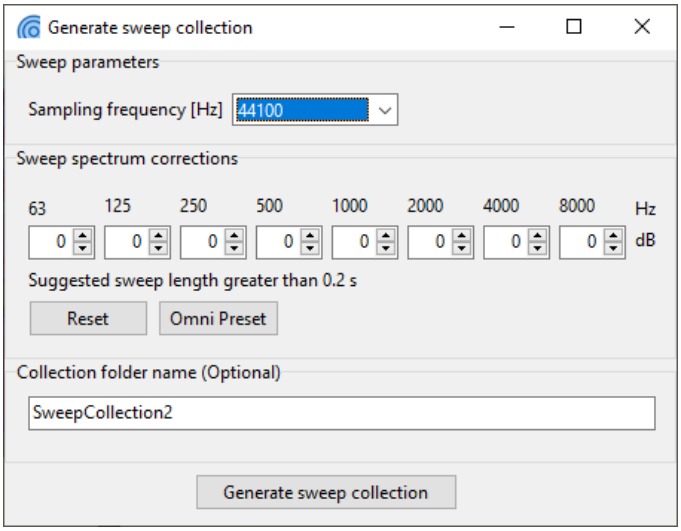


Note: performing the measurements directly with ODEON allows you to quickly check the quality of the measured impulse response, and to repeat the measurements immediately if something went wrong. This becomes more difficult when using exported sweeps. Therefore, we recommend you to be conservative when performing the measurements. Favour long sweep durations, and maybe repeat the measurements a couple times.

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Generate sweep collection

Click on Tools>Generate sweep collection to open the sweep generator window.



- **Sampling frequency:** choose between typical sampling frequencies for audio applications.
- **Sweep spectrum corrections:** modify the spectrum of your sweep to boost selected octave bands relatively to others. This feature works exactly the same as in the ODEON measurement tool (see Section 12.3), and it contains a preset to optimize the sweep specifically for the Odeon Omni source. The spectrum corrections are compensated for in the inverse sweep, so that you will obtain the room's impulse response when deconvolving the recorded signal.
- **Collection folder name (optional):** you can for instance specify which presets were chosen.

After clicking on Generate Sweep Collection, a list of .wav files will be generated. This can take a few minutes. At the end of the operation, the output folder opens in an Explorer window. The output folder is located in your ODEON folder in Measurements/Sweep Collections. The folder contains the following files:

- A list of sine sweeps for different frequency ranges and durations. The syntax of these files is "**OdeonSweep_[Frequency Range]_[Duration].wav**"
- The corresponding inverse sweeps. The syntax is "**InverseOdeonSweep_[Frequency Range]_[Duration].wav**"
- A text file called "**Odeon sweep parameters.txt**", which summarizes the parameters used during the sweep generation, as well as a list of the generated sweep files.

Below are the different sweep parameters applied by ODEON.

- **Durations:** 500 ms, 1 s, 2 s, 4 s, 8 s, 16 s, 32 s, 64 s, 80 s.
- **Frequency ranges:** 31 Hz-16 kHz, 63 Hz-8 kHz, 125 Hz-4 kHz, 125 Hz-8 kHz.

This makes a total of 36 different sweeps.

Note: if you want to use ODEON to import recorded sweeps at a later stage, please leave the generated sweep collection in the measurement folder.

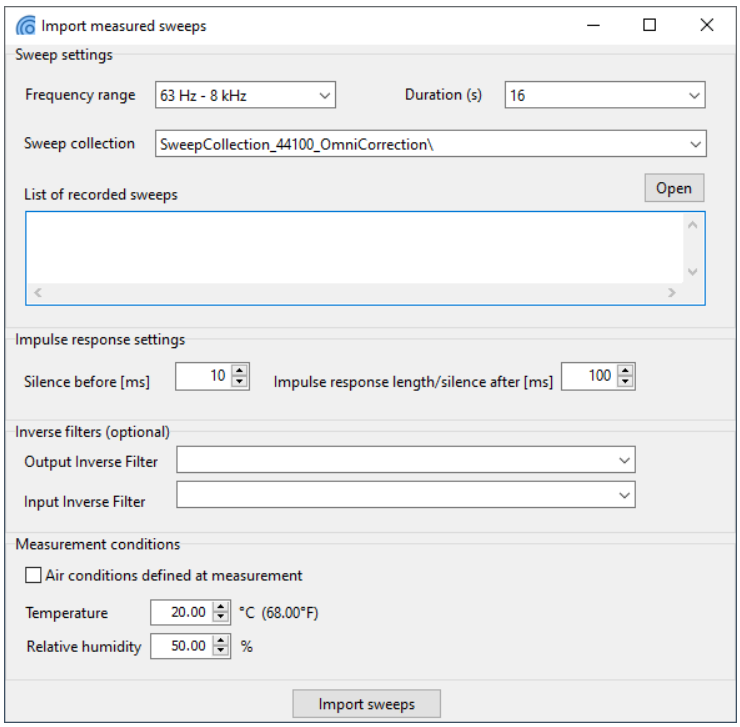
Measurements with generated sweeps

The sweeps can be played back and recorded with any equipment of your choice. You may also want to process it further (e.g., converting an A-format recording into a B-format recording). Once a sweep has been recorded and saved as a .wav file, it must be deconvolved to obtain the measured impulse response. This can either be done with or without ODEON.

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Import measured sweeps with ODEON

This menu allows you to import recorded sweeps into ODEON. You can easily import a series of recordings which used the same settings (frequency range and duration). Click on Tools>Import recorded sweeps to open the menu.



- Select the **frequency range** and the **duration** you used during the recordings.
- Select the sweep collection that was used during your measurements. The sweep collection must be stored in the Odeon folder Measurements\Sweep Collections.
- Click on **Open** and select all recordings that were made with the chosen settings. They will appear as a list in the dialog window.

Additional options from the traditional measurement system are also available. See Section 12.3 for more information.

Note: applying a source filter is not the same as modifying the sweep spectrum when generating the sweep. Sweep spectrum modifications will modify the SNR in every band, but the sweep spectrum is compensated for during the deconvolution.

Once you have entered all your desired settings, click on Import sweeps and select an output folder.

Deconvolving sweeps without ODEON

Recorded sweeps can also be processed outside of ODEON. Simply perform a convolution between your recorded signal and the corresponding inverse sweep.

You should follow the guidelines below when performing the deconvolution:

- The inverse sweep should have the same duration and frequency range as the sweep you recorded, so make sure to note them down during the measurements.
- The sampling frequency of your recordings should match the ones used in your sweep collection.

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- We recommend using linear convolution over circular convolution, to avoid wrap-around errors. With this convolution method, harmonic distortion will be separated from the signal and it will appear before the impulse response onset. You can then easily crop this part of the signal out.

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13 Genetic Material Optimizer

ODEON will then process the recorded sweeps and convert them into impulse responses.
(Combined and Auditorium editions only)

A very special feature of newer versions of ODEON, Auditorium and Combined, is a state-of-the-art optimization tool that allows you to refine the materials in a model in order to match the real acoustic conditions in an existing room. The tool is based on research presented in Forum Acusticum 2014, Krakow, Poland (Christensen C.L., 2014). A genetic algorithm is utilized in the optimization tool. The optimization process can also be called *material calibration* or *material tuning*.

Optimizing the absorption coefficients of materials inside an acoustical room model to match with measured data is a well-known problem among room acoustic consultants. So far, the task had to be performed manually in an iterative process of trial and error. The reason for requiring such an optimization process is that materials in an existing room are not completely known. For example, we might be able to know that the wall is made out of concrete but we probably cannot know the actual type of concrete and the corresponding absorption data. Usually, 5 to 15 materials are present in a room and most of them can be known to some degree.

Common parameters to evaluate in a calibration procedure are Early Decay Time *EDT*, Reverberation Time T_{30}, Centre Time T_s and Clarity C_{50}, C_{80}. Reverberation time is complementary to Centre time and Clarity, meaning when the one increases, the other decreases and vice versa. Among the numerous types of search algorithms, the ODEON optimization tool uses *Genetic Algorithms*, which are proven to be efficient for searching in multi-dimensional search spaces (multi-variable problems).

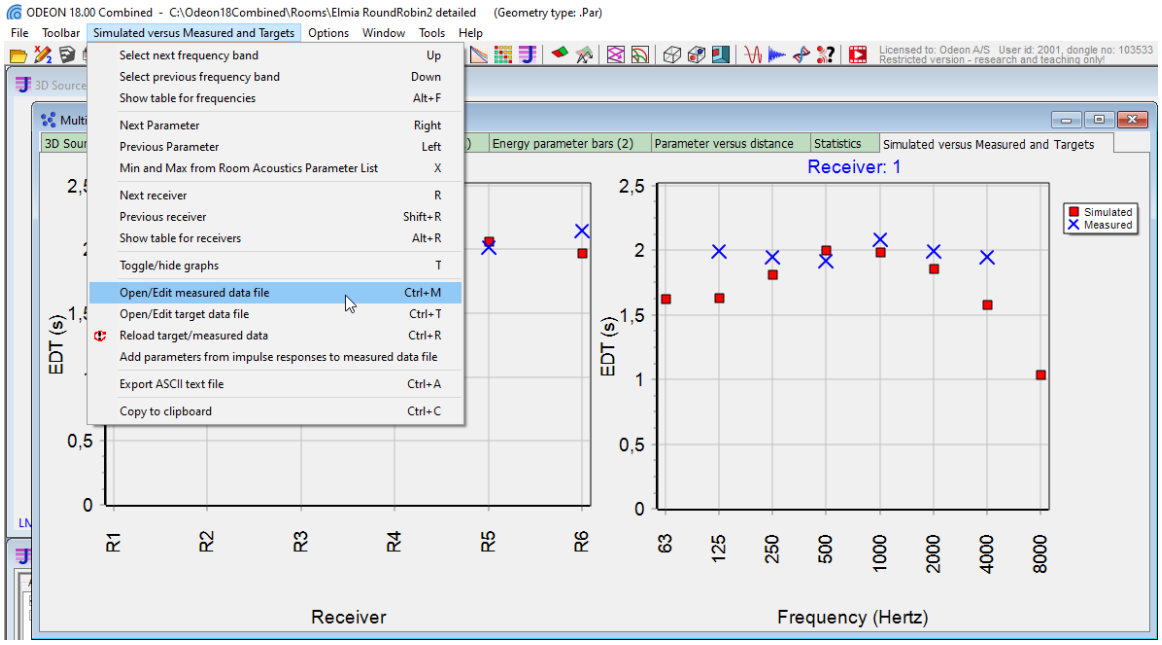
13.1 General Steps for Material Calibration

So far, any optimization process had to be done manually. With the Genetic Material optimizer tool in ODEON, the largest part of the process is done automatically, but the time to set up the calculations remains roughly the same. The general steps for a calibration are as follows:

1. Visit the room and inspect the walls. If no official data for the materials used on the natural walls are available, an initial estimation has to be done and the closest materials in the ODEON library should be assigned. Remember you can also add your own materials in the ODEON library by pressing the Add Materials (CTRL+M) button in the local toolbar in the Materials list.
2. A group of impulse response measurements should be performed using the ODEON Measuring System (see Chapter 12) or another application (see step 7). The measurements have to be done at known positions inside the room. The ISO standard 3382 presents the guidelines regarding the number of sources and receivers required for a given precision.
3. A virtual model of the existing room should be made in ODEON, where sources and receivers have to be placed at the same positions as in measurements.
4. Define one multi-point response job for each source in the room in the JobList.
5. The measured impulse responses should now be loaded in ODEON using the Load impulse response tool (see Chapter 12).

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6. After inspecting the measured results and paying attention to warnings, insert the room acoustic parameters into the multi-point responses defined in step 4. See Chapter 12 for how to import measurements to multi-point response.
7. If your measured data comes from another application as a .txt file, you can import them directly into the multi-point response.
   - Open the simulated multi-point response results for a selected job.
   - Click the Measured versus Simulated tabsheet.
   - Choose Open/Edit measured data file.



- Now you can enter the measured data. You need to follow the format shown below:

RECEIVER 1

T(30)	-	2,09	2,04	1,92	2,01	1,97	1,84	-
EDT	-	2.11	2,2	2.09	2,09	2.02	1.89	-
D(50)	-	0.1927	0.4857	0.4753	0.4519	0.5582	0.5768	-
C(80)	-	2.36	1.14	0.76	1,10	2.59	3.15	-
Ts	-	162,29	112,26	107,36	112,23	90,32	85,17	-
SPL	-	10,49	10,84	10,54	9,69	8,56	8,82	-
LF(80)	-	0.0062	0.0026	0.0067	0.0247	0.0458	0.0781	0.0273
STI	0.7							
SPL(A)	12.2							

RECEIVER 2

T(30)	-	2,20	1,95	1,99	2,01	1,76	1,81	-

Example of input file. Measured results for *Receiver 1* and *2* are to be imported. For Receiver 2 only the T_{30} parameter is available. In most cases parameters are only available for the 125 to 4000 Hz bands. For these a dash should be assigned to the 63 and 8000 Hz bands.

Remember: Click F1 while working in the Measured versus Simulated tabsheet to get the corresponding section in the help file, which includes instructions on how to merge measured results to simulations.

Manual Optimization

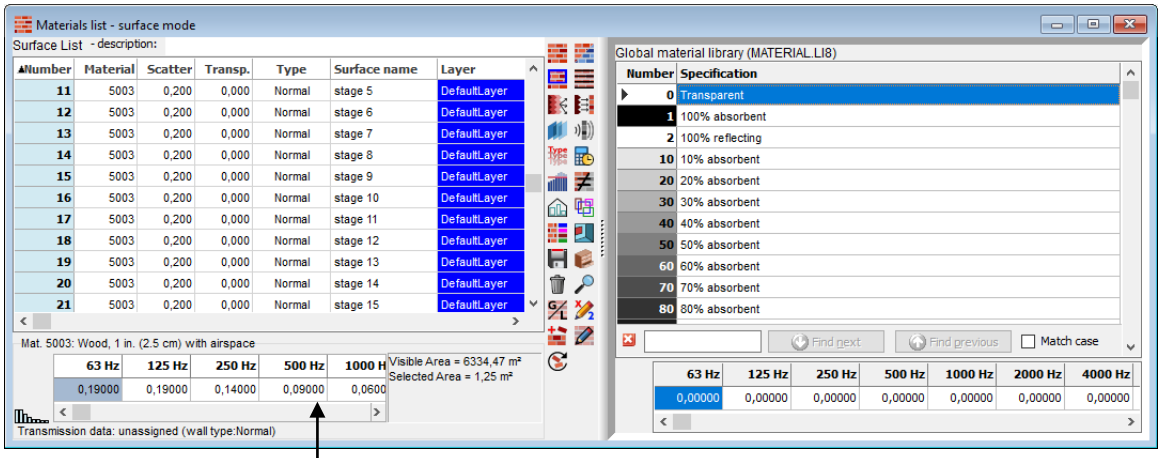
A manual optimization-calibration of a room model against a real one is based on trial and error. Usually, two complementary acoustic parameters have to be used. Complementary parameters are

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those ones which vary in different directions. A common pair is T_{30} with C_{80}. In principle as T_{30} increases, C_{80} decreases and vice versa. In addition, C_{80} is a rather sensitive parameter that varies highly with position. With an initial guess of materials, a first simulation has to be carried out. If measured results have been imported properly into the multi-point response, the Measured versus Simulated tabsheet will show the degree of the agreement. If the agreement is not satisfying, some materials need to be changed.

When small changes are needed for a material, there is no need to change or define a new material in the Global or the Room material library. You can just modify the absorption coefficient values on the surface list (left part), which will only affect the surfaces that use this material.

Remember: If you have to define new materials in the library you have the chance to make changes only for the library associated with the room. Press the Toggle between local and global room library button . The title on the top of the material library will change from Global material library to Room material library. Now, when you add a new material or delete an existing one it will not affect the default global library.



Change absorption coefficients here in order to leave the material in the list unchanged.

The best approach is to focus your calibration procedure on a few most critical materials (two or three) and try to vary them until you get the best possible match.

Example: In a classroom all materials are pretty well known except from the ceiling. An initial estimate for the ceiling is chosen and the first simulation shows higher simulated T_{30} than the measured one. The user has to go back in the Material List and increase the absorption of the ceiling so that the simulated T_{30} becomes lower and approaches the measured one better.

Genetic Algorithm Optimization

Instead of following the tedious manual optimization procedure described above, you can make use of the ODEON's feature called Genetic material optimizer. The tool makes use of Genetic Algorithms and tries to modify the absorption coefficients of selected materials in the room in order to achieve a good agreement between simulations and measurements. This optimization is done on the basis of room acoustic parameters. The user can determine which acoustic parameters should be involved in the process by changing their visibility in the Room Acoustic Parameter list . Before performing any calculation, it is worth getting familiar with the basic principles of Genetic Algorithms.

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13.2 How Genetic Algorithms Work

Genetic algorithms (GA) are widely used for optimization processes in diverse areas, such as industrial design, artificial life systems and economics. GA starts with an ensemble of individuals (chromosomes) and evolve new and improved individuals by applying principles found in molecular genetics and biology: crossover (recombination), mutation, etc. In any stage of the evolution the ensemble of individuals is called population and corresponds to one generation. An individual is essentially a candidate solution to the optimization problem and normally consists of more than one gene.

The criterion that is used from the evolution process to create an improved generation is the fitness function. Properties of the individual that give good fitness between simulated values and target values will have better chances of propagating into the following generations. The reason that GAs have become popular is their ability to find useful solutions in a very complex search space having many minima/maxima without getting stuck in the first occurring local minimum/maximum.

In our optimization problem there are eight different GAs that run independently for each octave band. Translating the foregoing terms to our problem, an individual consists of a complete set of absorption coefficients for a particular frequency band, corresponding to the different materials in the room. Henceforth we shall use the term "material" for describing its absorption coefficient. One material is one gene. The terms are shown in Table 13-1. All frequency-dependent GAs start with a random pass (Monte Carlo method) where all individuals of the population are generated with absorption coefficients which vary randomly according to a user specified search range. This can be called 0^{th} generation. After this pass, the evolution process is initiated by filtering out the best individuals as parents and producing children that are likely to inherit some of the advantages from their parents. The process continues indefinitely until the solution fully converges (criterion is satisfied) or until the user terminates the calculation. It is unlikely that the solution will converge fully in the acoustic optimization problem, so in practice, calculations are terminated by the user.

Target Value and Fitness Function

In order to evaluate how well a room simulation model with a given set of materials (an individual) matches against the measured room one needs a fitness function (see Table 13-1). The fitness function returns a number (fitness) to the GA that allows it to determine which individual (candidate solution) is better than others, controlling the genetic evolution. In our problem the GA seeks for individuals that minimize the fitness value, while in other GA problems the criterion might be a maximization of the fitness. In principle it can be considered to evaluate directly how well the simulated impulse responses match against the measured ones. However, there is bound to be differences between them as neither measurements nor simulations are perfect (Christensen C.L., 2014). Instead, we have chosen to compare how well some of the room acoustic parameters match - as these are supposed to be good measures for important attributes of the acoustics in a room. Indeed, a group of room acoustic parameters is one of the most important tools of the room acoustician for the evaluation of the acoustic quality. In order to evaluate the fitness of a set of materials, point responses for a number of source-receiver pairs are simulated and the average deviation of a number of room acoustic parameters is calculated. The parameters are normalized to their JND (Just Noticeable Deference) (ISO 3382-1, 2009) (e.g. 5% for reverberation time and 1 dB for C_{80}) so it is possible to merge different parameters into one fitness number. If the difference between measured and simulated parameter is less than 1 JND - e.g. less than 1 dB for C_{80} - this is

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fairly accurate as it is not possible for the human receiver to perceive the difference subjectively. The fitness function used is given by the following formula:

$$\varepsilon[JND] = \frac{\sum_{k=1}^{K} \sum_{i=1}^{I} [\mathrm{Par}_i^k]_{Sim} - [\mathrm{Par}_i^k]_{Meas}}{K \cdot I}$$

where ε is the fitness value (error between simulated and measured value) in *JNDs* and $[\mathrm{Par}_i^k]_{Sim}$, $[\mathrm{Par}_i^k]_{Meas}$ represent the simulated and measured acoustic parameter *i* for the source-receiver combination *k*. *K* is the total number of source-receiver combinations, while *I* is the total number of used acoustic parameters.

Table 13-1: Terms used in GA and their interpretation to the acoustic optimization problem.

GA Terms	Analogue to material optimization
Gene	Absorption coefficient of a material for a specific frequency band.
Chromosome	Set of genes (materials) that characterize an individual.
Individual	A candidate solution that consists of a list of genes (materials) - associated to a chromosome.
Population	Ensemble of Individuals - all different material combinations for one generation.
Generation	A stage in the evolution process corresponding to a population.
Evolution	Process of obtaining new sets of materials.
Target	Measured acoustic parameters.
Fitness	The error between simulated and measured data for an individual. Should be minimized.
Fitness function	Calculation of fitness according the formula presented previously.

Search Space

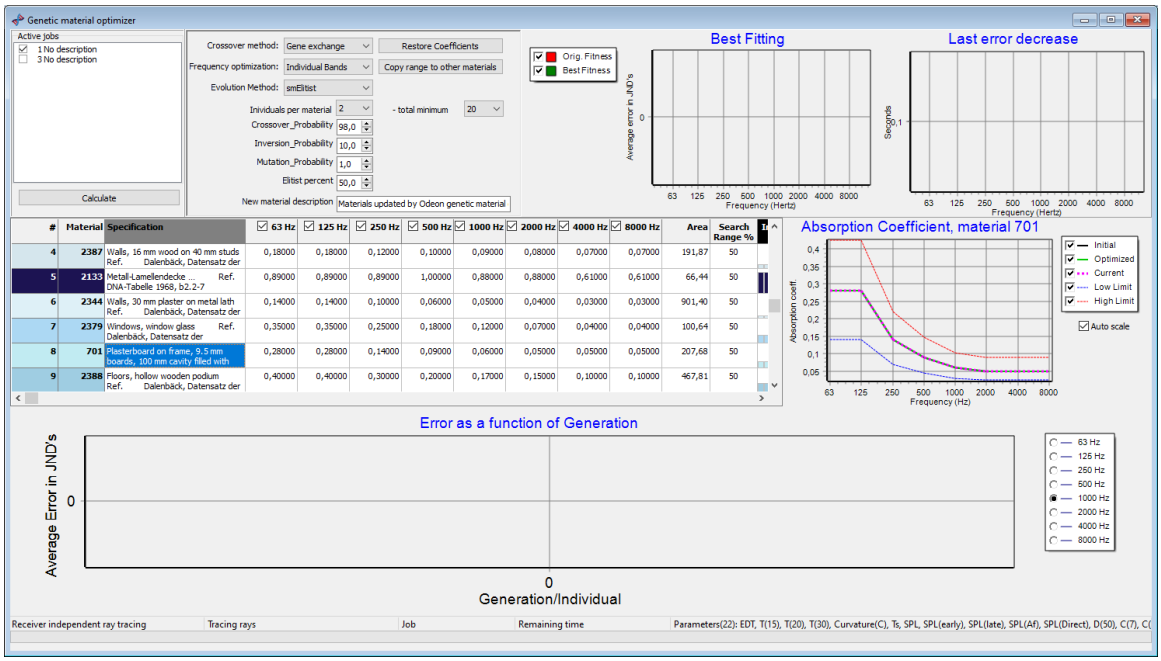
In order to optimize the search process, it is important to limit the search space. The search space can be limited by telling the GA that some of the absorption coefficients should only vary within certain limits and even that some should not be changed at all.

This variation can be called search range and is given in percentage. A value of 100% would lead to a search range from 0 to 1 absorption coefficient, regardless the initial values. A value of 0% leads to no change at all, meaning that the material is excluded from the optimization process. A search range between 0 and 100% gives lower and upper limits depending on the initial absorption coefficient. Careful estimation of the search range is crucial for achieving realistic solutions. For example, if it is suspected that two hard parallel walls may cause a flutter echo once extra absorption is installed in the refurbished room, then it is important to restrict the absorption coefficients and search range to low values e.g. maximum 2%. If a material is only installed on a small surface area or it is believed to be well known it may be assigned a search range of 0% - on the other hand there is always uncertainty when it comes to absorption coefficients, so leaving the search range to its default of 50% may often make sense. By limiting the range of absorption coefficients, the search process becomes more efficient as the GA will only search where there are possible valid solutions - e.g. if it is known that there is mineral wool in the ceiling, the GA should not specify absorption corresponding to wooden floor and vice versa. This will not only make the search faster, but it will also prevent unrealistic solutions which match the target well but are obviously wrong (wooden floor on the ceiling and mineral wool on the floor). It is recommended

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that the user initially assigns materials as realistic as possible. In the ODEON Genetic material Optimization tool it is possible to assign a search range between 0% and 100% to each material.

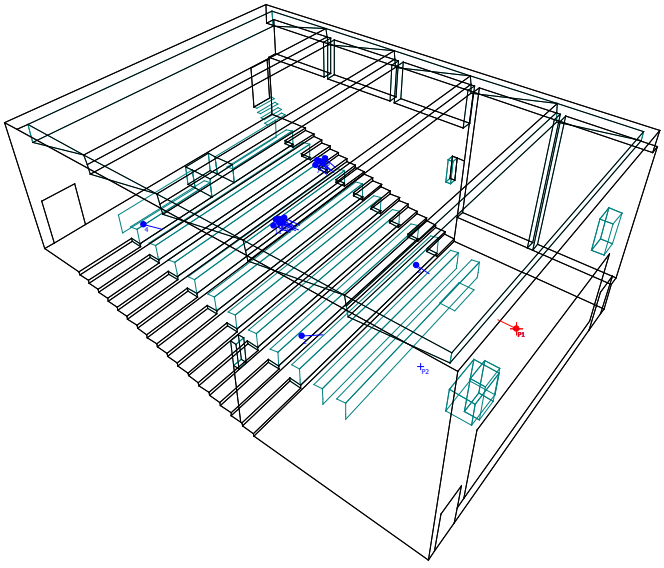
The interface of the Genetic material optimizer before any calculation has started. Later in this chapter an overview of



the different parameters is presented.

13.3 Perform a Material Optimization

The room Auditorium 21 at the Technical University of Denmark (DTU) will be used as an example. A wire frame is shown in the following figure:

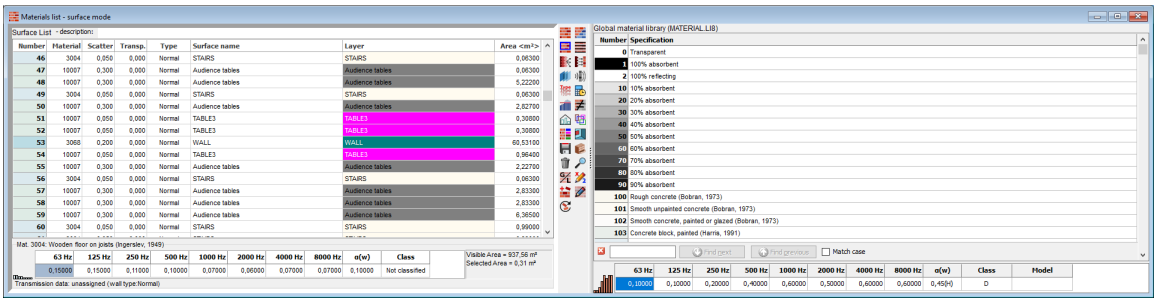


Load the room

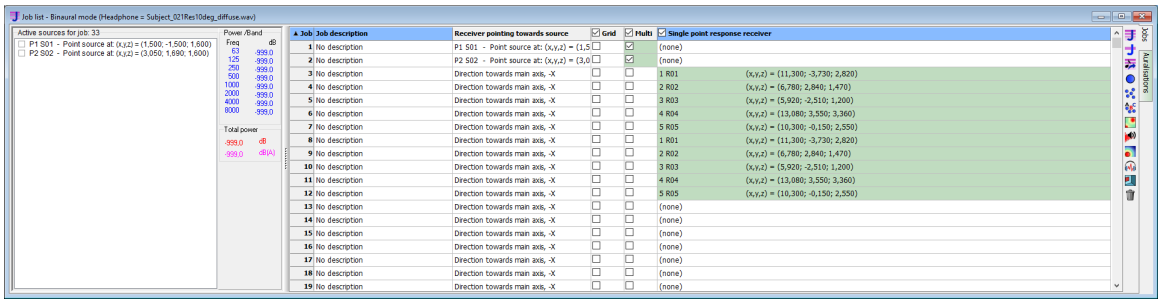
Open the room Auditorium 21 at DTU.par that is pre-stored in the ODEON's rooms folder (e.g. C:\Odeon…\Rooms), in the subfolder called Genetic Material Optimization – Auditorium21DTU. Inspect the room in the 3D View and have a look at the Source/Receiver list . Two sources and five receivers have

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been set, giving 10 combinations. Open the Material list . There are 11 different materials assigned to surfaces. The back wall, which is some kind of resonator panel with unknown resonance frequency, and ceiling are set to 50% absorption for all frequencies. In the real room it was not possible to inspect the ceiling material so an initial estimate is 2 x 13 mm gypsum board with mineral wool back.



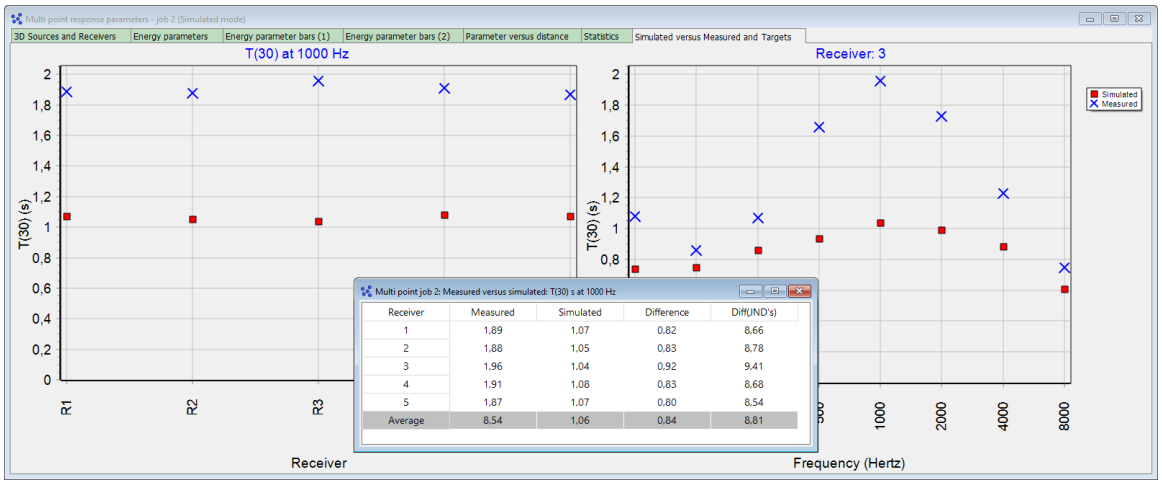
Have a look at the jobs defined in the Job list . The first two jobs are of particular interest, since they have the Multi point response enabled. The material optimization is done based on responses of multiple receivers and comparison to measurements. Run both Job 1 and Job 2 and see the results in the Measured versus Simulated tabsheet in the Multi point response results. The difference between



measurements and simulations for most of the parameters is significant.

Remember: In the Measured versus Simulated tab-sheet you can change receiver by hitting the R or Shift+R key, frequencies by using the Up/Down arrows, and parameters by using the Left/Right arrows.

Tip: Double - click on the graphs to get a table displaying the deviations between measurements and simulations in JNDs (Just Noticeable Differences).

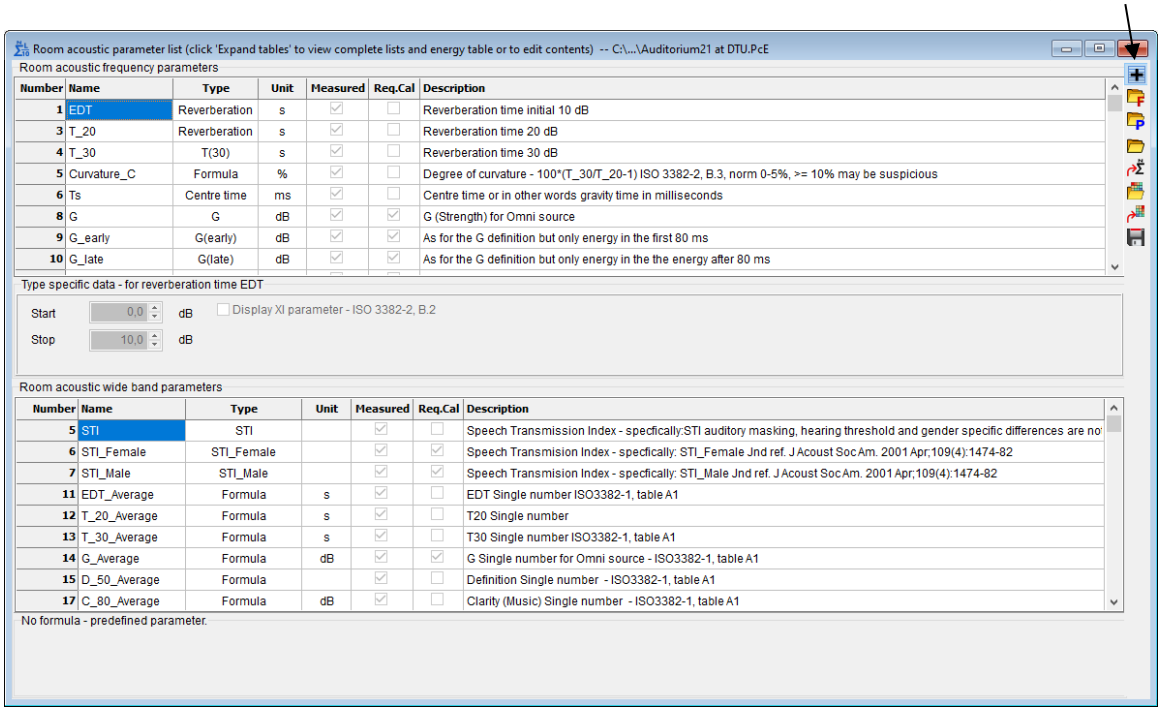


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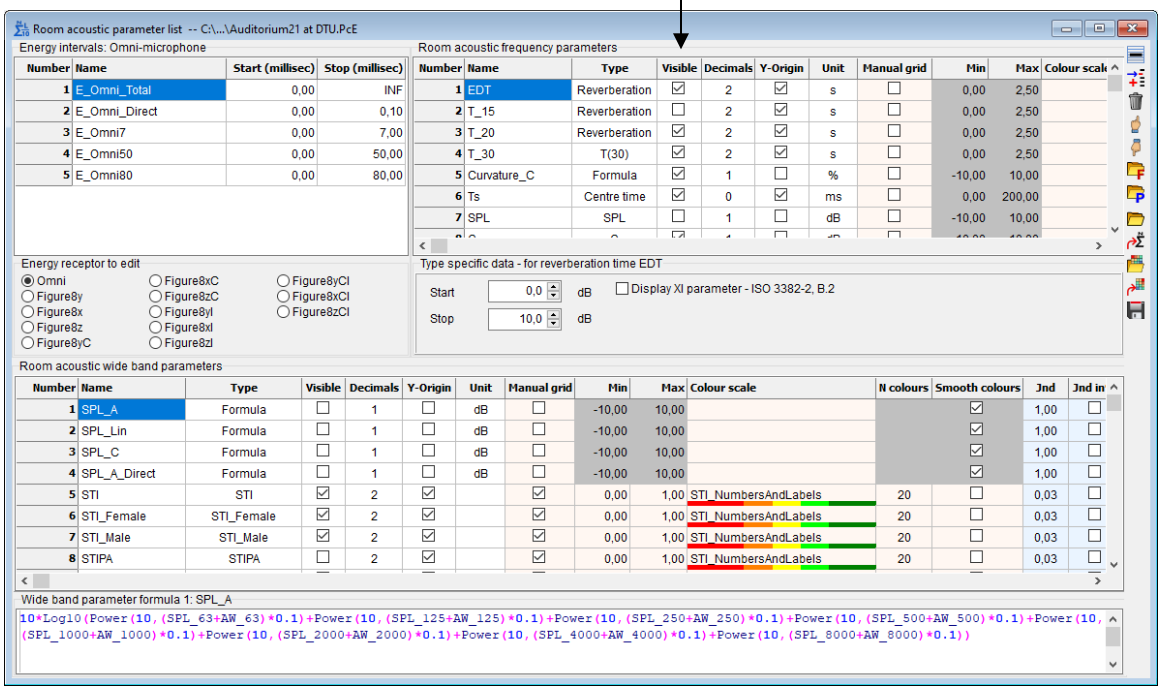
Choose Room Acoustic Parameters

Before starting the Genetic Material Optimizer , you may want to limit the optimization process to a selected number of parameters – not the default bundle. To do so, open the Room Acoustic Parameter list . Initially the list is collapsed showing only the active parameters (visible ones). To change the state of each parameter, click the Expand tables button at the top right corner. The window becomes like the one in the following figure. The visibility column appears where you can select which parameters will be displayed in the single point response, multi-point response and grid response. The selected parameters will be taken into consideration in the genetic material optimizer as well.

Click here to expand the list



Select the active (visible) parameters



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Which parameters to include

Reverberation-type parameters and fractional-type parameters are probably the best and more stable ones to use in a material optimization process. A common (but not unique) set can be:

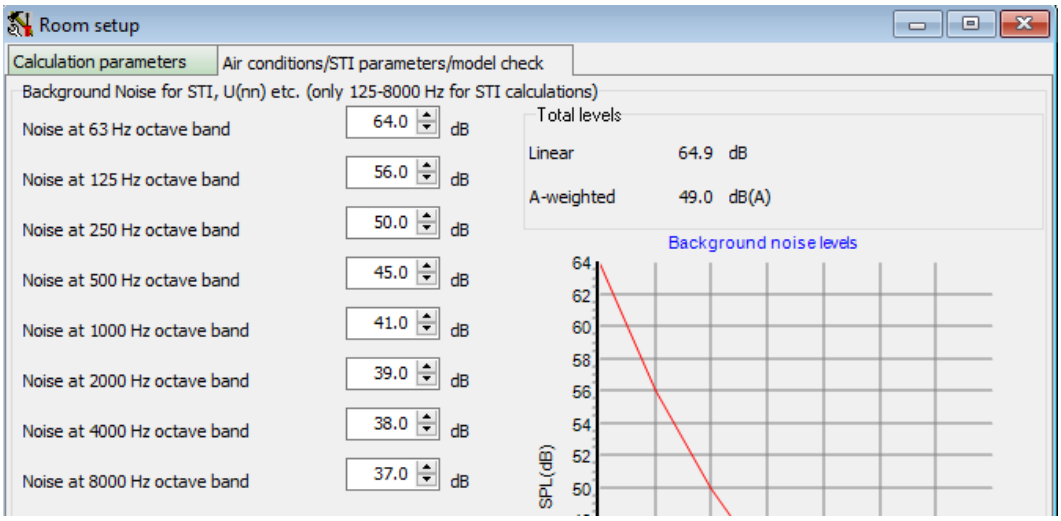
- *EDT*, T_{15}, T_{20}, T_{30} (reverberation parameters)
- T_s, C_{50}, C_{80} (fractional parameters)

Reverberation-type and fractional-type parameters have a high degree of complementarity among them. For example, if T_{30} increases, C_{80} degreases and vice versa. This makes the GA fitting process more accurate (although more difficult), because the algorithm tries to balance counter forces.

Which parameters NOT to include

There are certain parameters in ODEON that cannot be compared with measurements, because they are not calibrated with proper references. The optimization process can be ruined if you include such parameters, therefore it is important to uncheck:

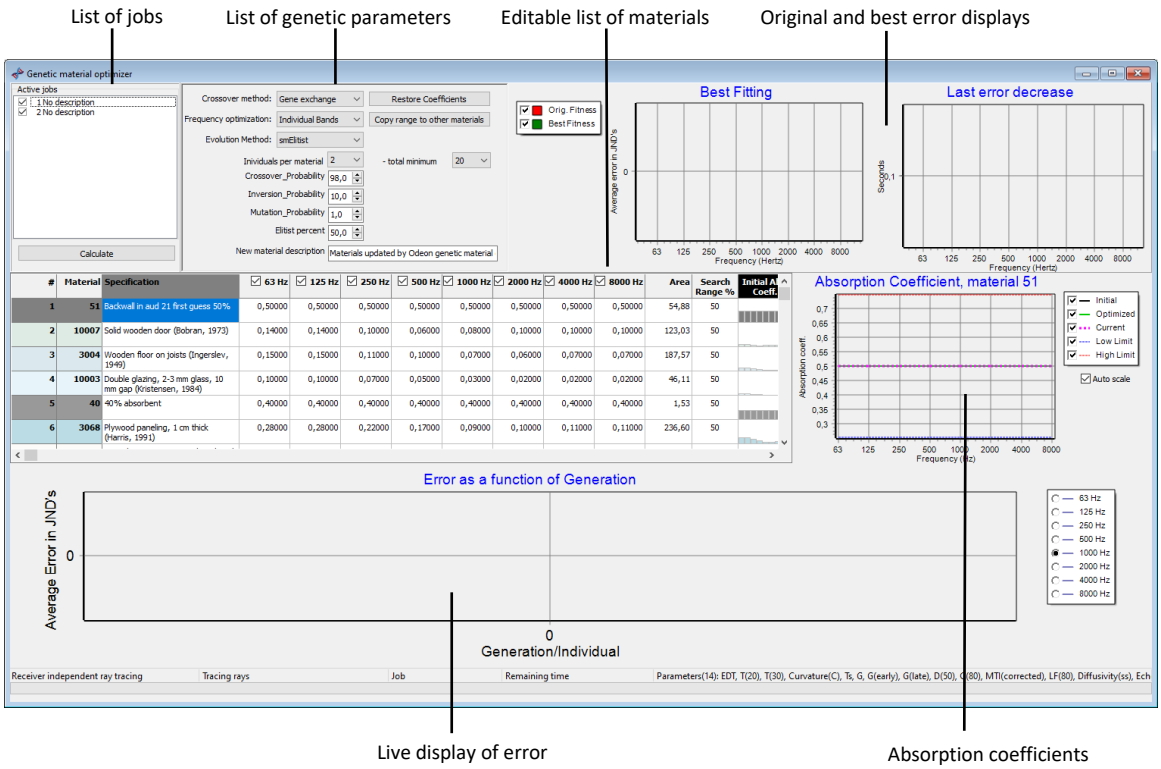
- All SPL parameters that have been obtained with the ODEON measuring system. At the moment it is not possible to calibrate the system using a *pistophone* at a standard level (eg. 94 dB or 114 dB) at a particular frequency (eg. 250Hz or 1 kHz). Therefore, any SPL parameter is not meaningful and typically very low compared to reality.
- G, G(early) and G(late) parameters, if the system is not calibrated for them. However, in contrast to SPL, it is possible to calibrate ODEON for G, according to Section 12.9.
- STI, STI(male) and STI(female) parameters, if the system is not calibrated for them. Similarly to G, there is a procedure to calibrate the system for including them. See Section 12.9.
- Although not-depended on calibration, parameters like *Curvature* and *Dietsch Echo* is better to be avoided because they are very sensitive on measurement conditions and background noise, therefore rather unstable.
- Clarity parameters that include background noise, such as U(50) and U(80) may be used if background noise has been carefully set in the Room Setup of the model. Ideally it has to be measured by an SPL meter inside the real room.



Open the Optimization Tool

Click the Genetic material optimizer button in the Main Toolbar or press the shortcut SHIFT+CTRL+Q. The interface should look like in the following picture:

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The following main areas are available in the interface:

List of Jobs: Jobs that have active sources and which has been assigned measured results are listed here. In this example, 12 jobs have been used in the JobList, while only two of those has been assigned measured room acoustics parameters as can be seen in the Multi point response displays of these jobs (simulations does not need to be completed to see measured room acoustics parameters). Multi point response's relevant to the optimization procedure are activated by default. Keep these first two jobs activated.

List of parameters: These parameters are for the research user of Genetic Algorithms only. As a common user you can leave the settings at their default values. Otherwise, you can read the green box with the title "Expert's parameters".

Editable list of materials: The list of materials as they have been assigned in the material list are displayed here. The materials can be edited and their absorption spectrum is illustrated directly on the right side. If absorption or measurement data are not well defined or measured for specific bands, you can exclude them from the search process by unchecking the associated column header. The allowed variation for each material during the optimization process is defined by the Search Range value. When this is 0%, it means that the material will not change at all, while when it is 100%, any absorption coefficient value can be assigned. When it is desired to exclude a material from the search process - to reduce the search space of the algorithm and to increase the speed - all that needs to be done is to make the Search Range value 0%. When calculations start, such a material stays inactive.

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Warning: Assigning Search Range 100% might be attractive because it allows any adjustment for a material and can lead to a very good match between simulations and measurements. However, the optimized material might be unrealistically different than the original material. Imagine beginning your search with a carpet material on the floor and ending with a variation of glass.

Extra functions for materials: Two buttons allow more flexibility when editing the list of materials: *Restore coefficients.* The button restores the absorption coefficients in all octave bands for the selected material. It is useful when you have started modifying the coefficients for a material and want to return to the original coefficients.
Copy range to other materials. If you have modified the Search Range of a material (default value is 50%), you can assign the same value to all materials by pressing this button.

Original and best error displays: The *Best Fitting* graph presents the original error between simulations and measurements versus the best value so far. The error is represented in JNDs. The *Last Error Decrease* shows the time elapsed since the last update of the best value so far, at the *Best Fitting* graph.

Live display of error: Here the error for every individual (solution) per generation is shown. Normally the error fluctuates highly in the beginning of an optimization process and becomes smaller and smoother as the genetic algorithm converges.

Absorption coefficients: Three different lines of absorption coefficients are updated constantly during a calculation.

- The *Initial* line corresponds to the absorption coefficients of the original material.
- The *Optimized* line shows the absorption coefficient that provides the best results so far.
- The *Current line* corresponds to the absorption coefficient of the currently running solution (which may or may not be a good solution).

Additional to the three constantly updated curves, two fixed are displayed:

- The *Low limit* specifies the lowest values the corresponding material can be assigned per octave band during the optimization process. It directly depends on the Search Range value.
- The *Upper limit* specifies the highest values the corresponding material can be assigned per octave band during the optimization process. It directly depends on the Search Range value.

Tip: For a direct comparison of different materials uncheck the Auto scale option. Then 0 becomes the minimum value and 1 becomes the maximum one.

Run a calculation

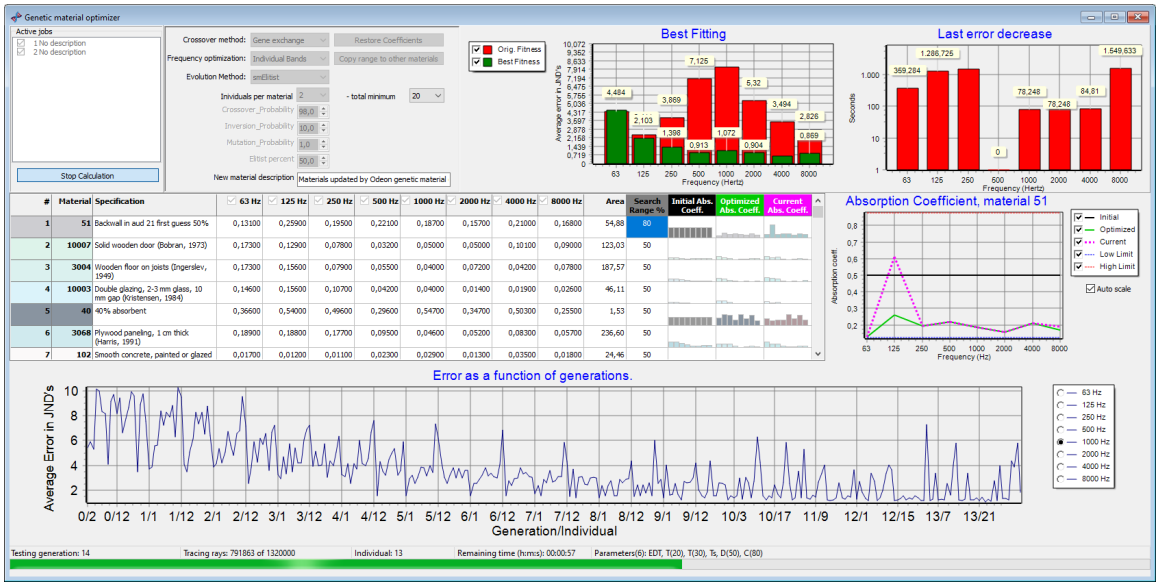
Now it is time to run a first calculation. Press the Start Calculation button. ODEON starts a preliminary run, during which the original fitness values are evaluated (red bars in *Best Fitting* graph). Depending on the problem this step can be extremely fast - almost unnoticeable.

Just after the preliminary run, the main Genetic Algorithm starts with the 0^{th} generation that involves generating completely random individuals (list of materials). However, this random search is always restricted between the low and the upper limits specified by the search range for each material. For example, a material that has been assigned a search range of 5% it will remain almost the same as the original even during the random 0^{th} generation.

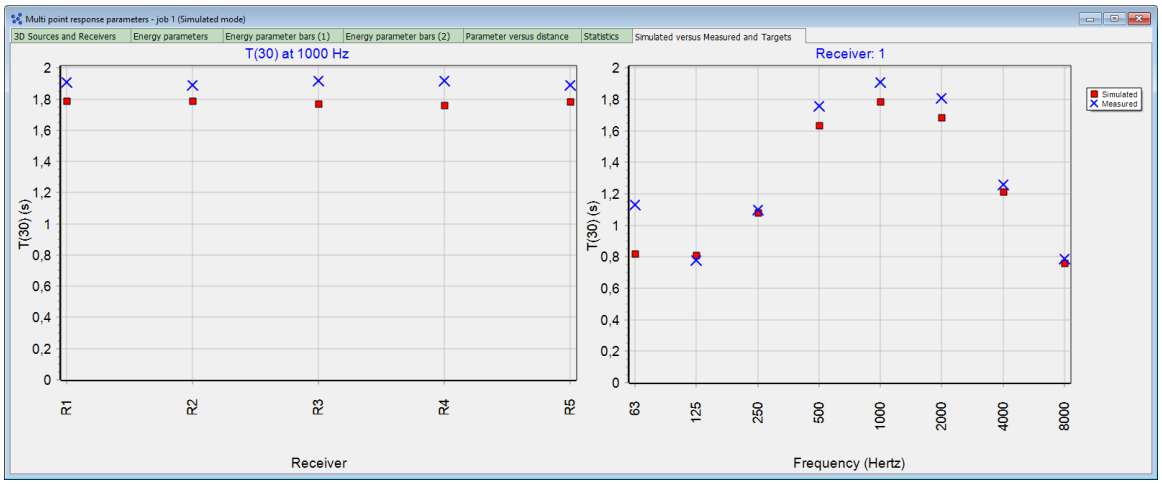
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After the 0th generation is finished, parents are selected with one of the methods described in the Expert's parameters. Then they start to evolve the next generation. From now on, the generation of new individuals is not random. This procedure will continue until you press the Stop Calculation button.

During the whole evolution process, all graphs in the interface are updated constantly. The following picture shows a screenshot after about 7 generations in a calculation. You can find the calibrated room in the Rooms folder with the name Auditorium21 at DTU_Calibrated.



Now have a look again at Multi point response for jobs No 1 and 2 in the Job list . The deviation between measurements and simulations for most of the parameters has been reduced significantly. Double click on the display to get a table with the differences in JNDs.



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Expert's parameters

Crossover Method: Defines the way individuals mix together to form a new individual. Two options are available: **Gene exchange** and **Vector mixing**. With the Gene exchange option, new individuals are created completely genetically by re-arranging.

Frequency optimization: When the *individual bands* option is selected, Genetic optimization is applied for each band independently. When *broadband scaling* is selected, optimization is performed using an average fitness value across all octave bands. This option aims to optimize the materials, while maintaining the exact shape of the absorption coefficient curve.

Evolution Method: Controls how parents are selected for generating new individuals. Five options are available:

Roulette: Parents are selected based on a "roulette-wheel" selection. Each parent is assigned a portion in the "roulette-wheel" according to its fitness. Parents with higher fitness value are more likely to be selected.

Random: Parents are selected completely randomly.

Tournament: A fixed number of individuals are selected randomly from the whole population. This is a "Tournament Field". Only the best parents are kept from this field. This process is repeated several times until a specified number of the best individuals is collected.

Stochastic Tournament: The best parents from a Tournament Field are selected by selecting better fit individuals proportional to the number of individuals per generation.

Elitist: The top n% of the population is chosen and re-chosen.

Individuals per material: A sufficient population of individuals is needed for a genetic evolution. By default, 2 individuals per material are generated. For example, if we use 10 materials in our search, 20 individuals will be included in the procedure. Other common values are 4, 6 and so on. The values always need to be multiples of 2.

Crossover Probability: Determines which portions of two parents will be combined to create two new offspring.

Inversion Probability: Controls the likelihood that inversion will occur in a child's chromosome, e.g., whether a portion of the child's chromosome will be flipped. The probability is between 0 (never) and 1 (always).

Mutation Probability: Controls the likelihood that each bit of a child's chromosome will be mutated (flipped) between 0 (never) and 1 (always). When 2 parents reproduce and create a new child, their chromosomes are combined using Crossover and then the child's chromosome may be mutated.

Elitist percent: Describes the percentage of "elite" parents used every generation for evolution. When this percentage is 0 it means no elite parents are chosen. When this is 50%, it means that half of the parents are selected as elite. The best 50% are chosen.

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14 Source Power Estimation

(Industrial and Combined editions only)

The Source Power Estimation tool fits Sound Pressure Level (SPL) measurement data to your ODEON model in order to estimate the power spectrum of one or multiple active sources. Both the SPL measurements and the sources' powers are frequency-dependent data, presented in 8 octave bands in ODEON.

The source power is expressed as a sound power level in dB, using the reference power of 1 pW = 10^{-12} W. Source power levels are typically measured in a reverberation chamber (ISO 3741, 2010), or in a free field over a reflecting plane (ISO 3744, 2010), which is not always practical, for instance for large equipment. It can also happen that the noise in a room originates from several sources, which cannot be measured separately. Therefore, the Source Power Estimation tool can be a good alternative in cases where the power of sources is a priori unknown.

14.1 Mathematical background

As a first step, the contribution of each source to each receiver is calculated by ODEON using the initial power values input by the user. The SPL at a given receiver can be understood as a weighted combination of these contributions.

A cost function is implemented to measure the fitness of data between the ODEON simulation and the measurements,

$$f(x) = \|\mathbf{y}_{sim} - \mathbf{y}_{meas}\|^2,$$

where $\mathbf{y}_{sim}$ and $\mathbf{y}_{meas}$ represent the simulated and measured sound energies at the measurement positions.

An independent optimisation problem is solved for each frequency band, in which the cost function is minimized using a sequential quadratic program for non-linear constraint optimization based on the **Trust Region (TR)** method. Different termination criteria are considered to stop the search:

- Optimality condition met under certain tolerance.
- Too small step towards the minimizer or too small TR radius.
- Maximum number of iterations reached.

Note that the variables of the optimization problem are **the power levels of all the active sources in a selected job,** and even though they are displayed in dB (logarithmic scale) the optimization problem is solved in energy (linear scale).

We typically recommend more measurement points than unknown source power levels (in other words, more receivers than sources). In that case, the problem is *overdetermined*, and it almost certainly does not have an exact solution. Therefore, we do not expect a perfect fit between $\mathbf{y}_{sim}$ and $\mathbf{y}_{meas}$. There will always be uncertainties in the measurements, especially due to background noise, as well as in the simulations. In addition, the uniqueness of the solution is not guaranteed, especially if too few measurements are taken. See below for further recommendations.

A sensitivity analysis is also performed in order to evaluate the stability of the solution. Each estimated power is varied while keeping all the other powers fixed, and an upper and lower bound

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are found within which the cost function varies less than 10 %. This means that the solution is not much affected as long as the estimated powers remain within their respective bounds. This is graphically displayed by error bars on the estimated sound powers.

It is expected that inaccuracies in the measured data (typically 1-2 dB) as well as imprecise modelling of the room (i.e. unrealistic room materials, deviation in receivers location, etc.) have an impact on the estimated powers. In this chapter, an explanation on how to interpret the results is given, along with a best practice guide to use the tool.

14.2 Perform a source power estimation

The estimation is based on the **measured SPL at different locations in the room**. You will need an accurate model of the room in ODEON to ensure meaningful results. For this guide we use the room PowerEstimation_HallWith2Machines available in the default rooms with ODEON *Industrial* and *Combined* installations. It is important to note that this room uses simulated SPLs as measurements. In general, the guidelines bellow must be followed:

- The geometry of the model should agree with the actual room.
- Make sure that the surface properties are realistic. You can make use of the Genetic Material Optimizer in order to calibrate your model (see Chapter 13).
- Use realistic models of noise sources: choose their nature accordingly (point source, surface source, line source) and assign realistic directivities to point sources.
- For multiple active sources, the estimation works best in not too reverberant spaces, where larger spatial variations of SPLs can be measured. In a completely reverberant space, we expect the SPL to be approximately the same everywhere, which makes it difficult to differentiate the different sources.

The accuracy of the results depends greatly on the choice of measurement points.

- It is advantageous to place measurement points relatively close to the sources.
- Avoid being too close to sources, as the near-field is less reliable to calculate in ODEON. For multi-surface sources, we recommend keeping the receivers not closer than the largest dimension of the source.
- We recommend 3-5 measurements per source.
- If possible, measure the SPL in regions which are affected mainly by one source.
- It can be beneficial to estimate the sources separately, if they can be turned off in real life.
- The receiver positions should be correctly specified in the ODEON model.

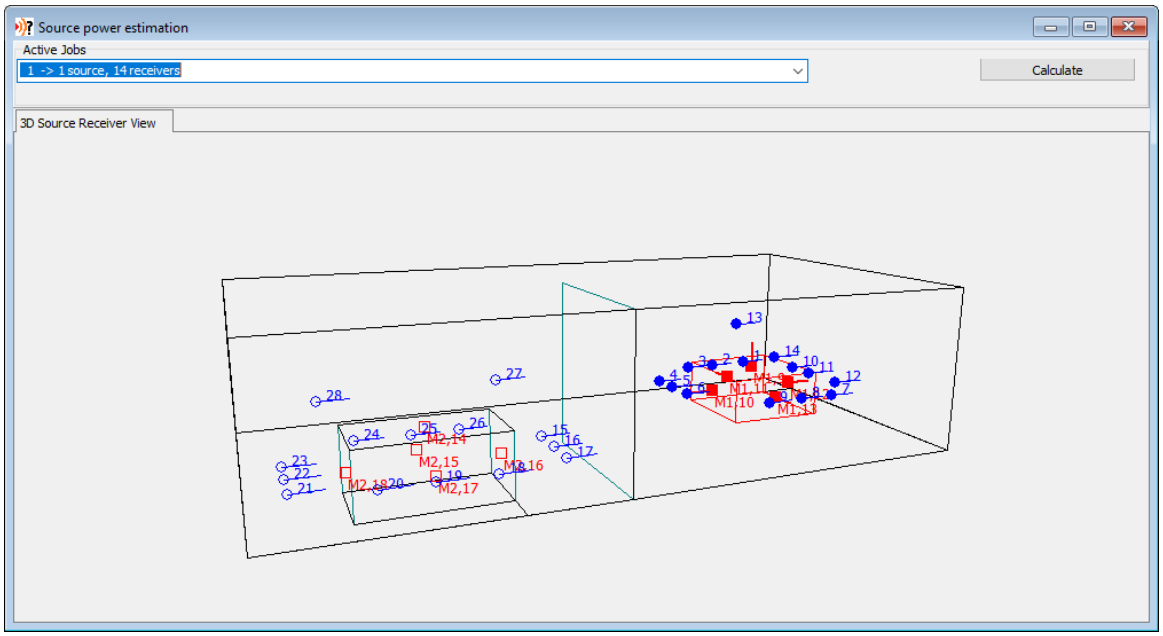
SPL measurements are typically made with a sound level meter; we assume that the measured noises are stationary during the measurements. In your room's ODEON model, add the SPL measurements to your multi-point response (see Section 12.6). Below is an example of measured SPL data formatted for ODEON:

```
Receiver        1
SPL     68.3    68.3    68.2    68.2    68.2    68.1    68      67.7
Receiver        2
SPL     68.2    68.2    68.1    68.1    68.1    68.1    68      67.6
Receiver        3
SPL     67.6    67.7    67.6    67.5    67.5    67.5    67.4    67
Receiver        4
SPL     66.1    66.1    66      65.9    65.8    65.8    65.7    65.2
Receiver        5
SPL     66.4    66.4    66.3    66.2    66.1    66.1    66      65.6
Receiver        6
SPL     65.9    66      65.8    65.7    65.6    65.6    65.5    65
```


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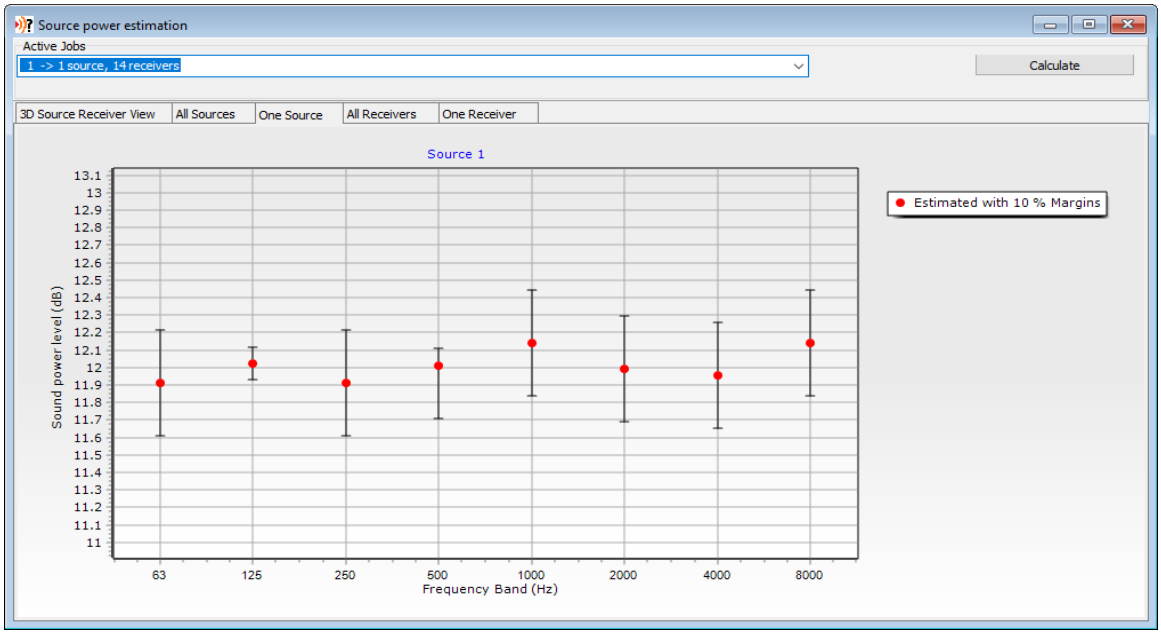
Remember: if data is missing in a frequency band, it should be indicated by a dash (-) instead of a value.

Open the Source Power Estimator and select the corresponding job in the upper drop-down list. The items of this list show the **job number**, the **number of active sources** and the **number of measured receivers** (only the jobs with measured SPL data are displayed). The 3D display shows the active sources and the measured receivers for the selected job.



Press Calculate to estimate the source power levels. Depending on the number of sources and receivers and the complexity of the model, the calculation may take a while.

14.3 Analysing the results



The results are presented in 4 tabs:

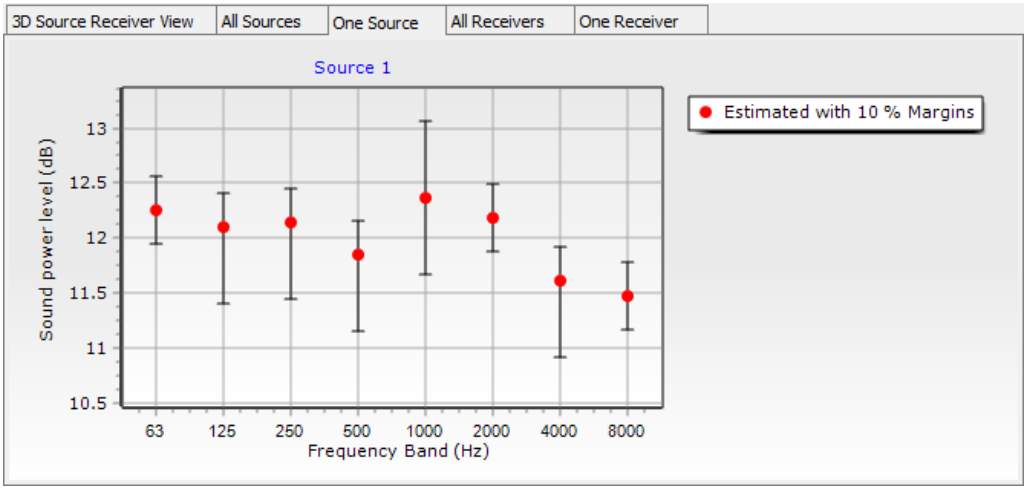
- **All sources:** shows the estimated sound power levels of all active sources for a given octave band. You can browse through the octave bands using the up and down arrows.

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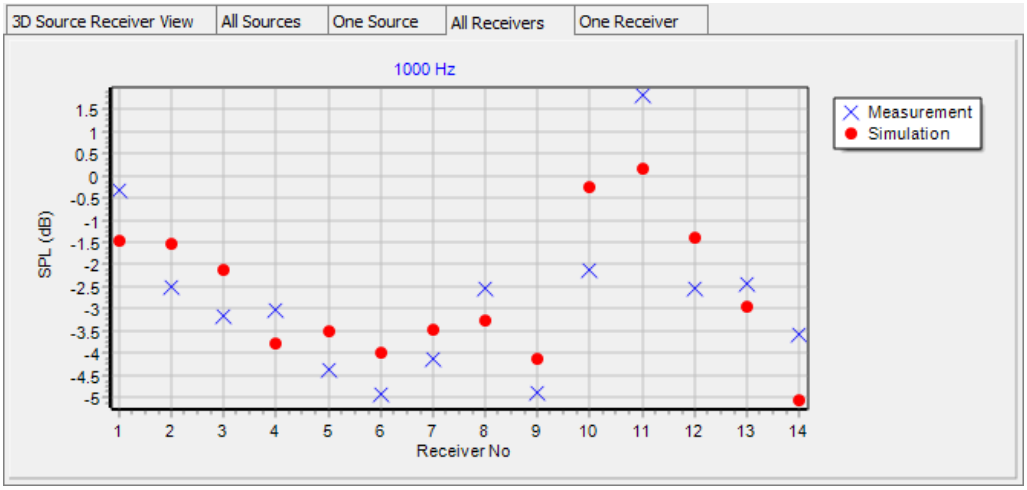
- **One source:** shows the estimated sound power levels for one given source at all octave bands. You can browse through the active sources using the left and right arrows.
- **All receivers:** shows the estimated and measured SPLs at all receivers for a given octave band. You can browse through the octave bands using the up and down arrows.
- **One receiver:** shows the estimated and measured SPLs of one receiver at all octave bands. You can browse through the receivers using the left and right arrows.

In the tabs showing the source powers (**All sources**, **One source**), error bars indicate the sensitivity of the estimation. They show how much the power of the source can vary so that the resulting cost function remains within 10 % of its optimal value. A large error bar can be explained by several factors:

- The source does not contribute significantly to the receivers (for instance if it is behind a partition wall). Therefore, its power does not matter and it is recommended to remove it from the list of active sources.
- The source has a much lower power than the other ones, which should be visible in the estimation. If this occurs in all frequency bands, it is better to leave the source out of the estimation problem.



The two receiver tabs (**All receivers**, **One receiver**) show the fitness of data between the measured SPLs and the simulated SPLs with the estimated source powers. Overall, you should expect a fair agreement between them. Measurements and simulations will generally not fit perfectly, because there can be uncertainty in the measured data (e.g., due to background noise), or differences between the real-life scenario and the ODEON model.



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After the calculation, you can either save the estimated powers or keep the original ones.

Note: The sound power levels in octave bands are saved in the EQ of the source, while the gain is automatically set to 0.

14.4 Summary of the general steps

1. Identify noise sources, and determine if they can be measured one at a time. We assume noise to be stationary.
2. Perform SPL measurements in octave bands around the sources at known positions (3-5 positions around each source).
3. Create an ODEON model of the room: pay attention to accuracy (geometry, material properties).
4. In the Source Receiver list, add sources to model the noise sources in the room. Accuracy is also essential (position, nature of sources, directivity for point sources).
5. In the Source Receiver list, add receivers at the same positions as in the measurements.
6. Define relevant multi-point responses in the Job List, with the proper active sources.
7. Add the measured data to the relevant multi-point response(s).
8. Open the Source Power Estimation tool .
9. Select the proper job and launch the calculation.
10. Inspect the results (estimated powers, fitness of data with measured SPLs).
11. When closing the tool, either save the new estimated powers or keep the original ones.

14.5 Best practice guide to optimise your results

Sources

- Include only the relevant sources, which contribute to noise levels at the receiver positions.
- The algorithm might struggle to distinguish two sources placed too close to each other. In that case, consider representing the sources by only one source. Alternatively, use additional receivers to differentiate them.
- The application is able to detect blocked sources and receivers and to exclude them from the calculations (a warning is displayed before the calculation starts).
- If two sources have very different powers, the stronger one will mask the weaker one, so you won't be able to properly estimate the weaker source.

Receivers

- Ideally, each receiver should be representative of a given source. We recommend 3-5 receivers per source, so that you have more measurement data than unknown source powers.
- A good compromise with respect to source-receiver distance must be found. Avoid the near-field of the source, but stay relatively close to the source, so that the receiver is heavily dependent on the source's power.
- Receivers should not be too close to each other, otherwise the measured SPLs will be redundant.

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15 Building acoustics module

(Auditorium and Combined editions only)

Since version 19, ODEON provides the possibility to calculate the sound insulation properties of a partition wall that separates two rooms, out of measurements carried out in both spaces. The new interface is called Building acoustics and it has been based on the ISO standard 10140 'Laboratory measurement of sound insulation of building elements', Parts 2 (ISO 10140-2, 2010) and 4 (ISO 10140-4, 2010).

15.1 Reduction index

The sound insulation of a wall is expressed by the Reduction Index R (dB), according to the following formula, based on the diffuse-field assumption:

$$R = L_S - L_R + 10log_{10}\frac{RT_R \cdot S}{0.16V_R} \qquad \text{Eq. 15-1}$$

where:
L_S is the average sound pressure level in the *source room*, with the sound source in the *source room*.
L_R is the average sound pressure level in the *receiver room*, with the sound source in the *source room*.
RT_R is the reverberation time inside the *receiver room*, with the sound source in the *receiver room*.
S is the surface of the wall under measurement.
V_R is the volume of the receiver room.

When $S = 10\ m^2$ then the formula above gives the Normalized Reduction Index NR (dB).

The measurement procedure for calculating the Reduction index is illustrated in the following figure. It should be noted that the sound pressure level has to be measured in the source room and the receiver room with the same sound source located in the source room. However, the reverberation time needs to be measured with a source in the receiver room.
For illustration purposes only one source and two receivers are shown in each room, but in reality, more source and receiver positions should be used for a reliable average.

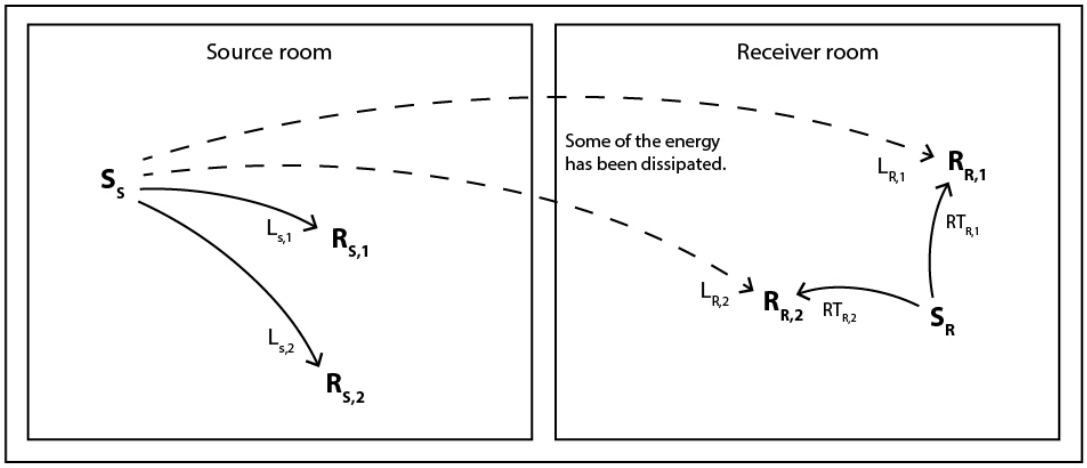


Figure 15-1: Measurement procedure for deriving the Reduction index of the middle wall, according to the formula above. To obtain average levels in both rooms, as well as the reverberation time in the receiver room, many source and receiver positions should be used.

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15.2 ODEON's Building acoustics interface

The Building acoustics interface in ODEON can be accessed via Tools>Building acoustics or by the button in the main toolbar . The interface is divided into three sections, as shown in the figure below:

Settings

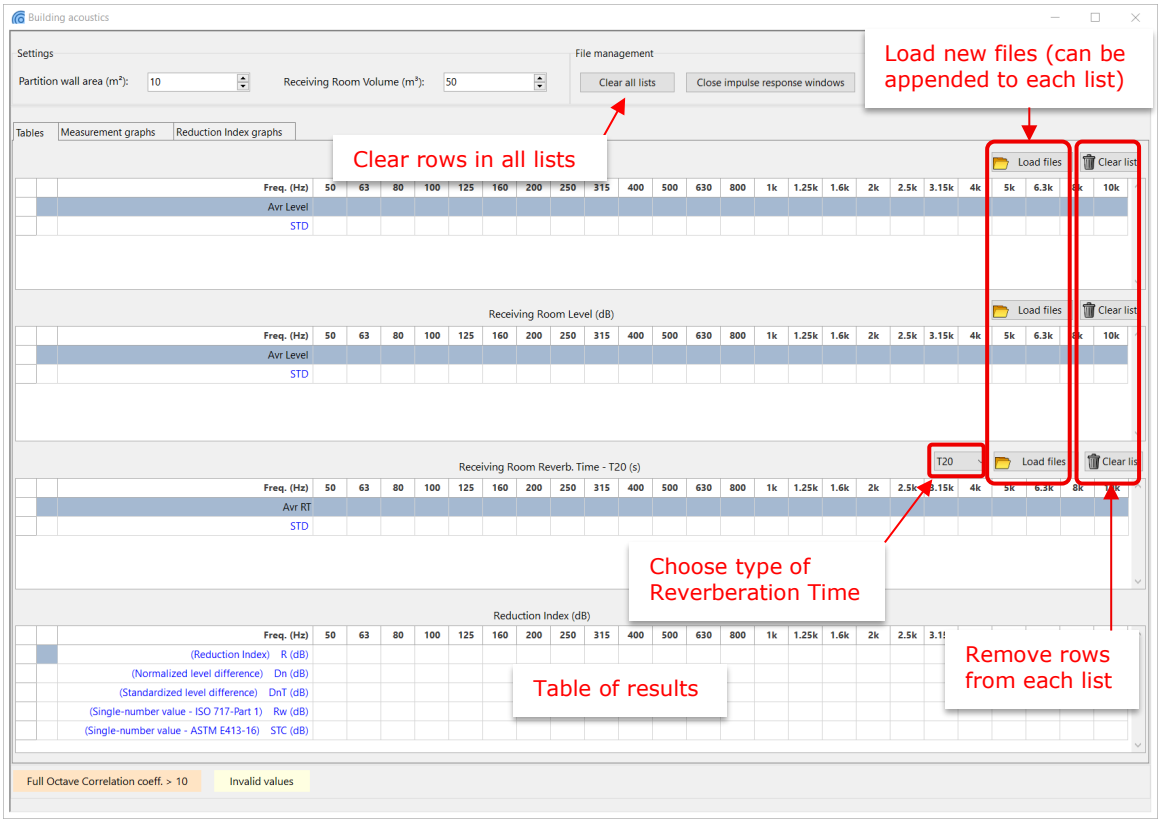
The surface of the partition wall and the volume of the receiver room are specified.
File management, where you can load new files and perform a variety of other file-management actions.

File management

Perform bulk operations on files that have been loaded in the interface.

Tables & Graphs

Shows the sound levels, the reverberation time and the reduction index calculation of the loaded files in tables and graphs. You can keep adding new files in the existing lists, until you press the Clear list or Clear all lists buttons to remove them from the lists.
The Reverberation time drop down allows to choose the type of reverberation time to be used in the calculation, among four options (T_{10}, T_{15}, T_{20} and T_{30}). We recommend to use T_{20} or T_{30}.



Calculated parameters

The Building acoustics interface provides results in 1/3 Octave bands, throughout an extended frequency range from 50 Hz to 10 kHz (while the ISO standard 10140 requires only bands from 100 Hz to 5 kHz). The following parameters are calculated (see full analysis in (Rindel, 2018)):

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- **Apparent Reduction index, R (dB),** as calculated from Eq. 15-1.
- **Normalized level difference, D_n (dB),** calculated from Eq. 15-1, with area S =10m². This parameter overcomes the problem of an unknown partition area. A common example is *staggered rooms*, meaning that the source and the receiving rooms are located with an offset, resulting to a very small area S.
- **Standardized level difference D_{nT} (dB):** An alternative to the previous parameter, calculated from the following equation, where there is no involvement of the partition area:

$$D_{nT} = L_S - L_R + 10log_{10}\frac{RT_R}{RT_0} \qquad \text{Eq. 15-2}$$

where RT_R is the reverberation time inside the *receiver room* and $RT_0 = 0.5\ s$.

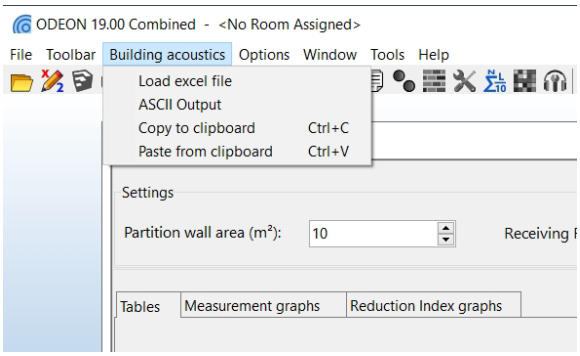
- **Weighted sound reduction index, R_w (dB):** A single-number rating which makes comparisons of sound insulation and specification of requirements more practical. The weighted sound reduction index has been defined in (ISO 717-1, 1996) and is calculated by comparing the measured reduction index with a reference curve, defined in 1/3-octave bands from 100 Hz to 3150 Hz (see full procedure in (Rindel, 2018)).
- **Sound transmission class STC (dB):** This is also a single-number rating defined in (ASTM E413-16, 2016), very similar to R_w, but for a frequency range from 125 Hz to 4000 Hz.

Load measurement files

You can obtain impulse responses with ODEON's Measuring system to be used for calculating the **levels** in the *Source* and *Receiving* room, as well as the **reverberation time** in the *Receiving* room. Use the Load files buttons and select one or multiple files, using the CTRL or SHIFT keys. You can always go back in any section to add or remove files.

Note: When deriving sound insulation parameters, what matters is the relative level difference between the Source and Receiving room, i.e., on either side of the partition wall. This allows the use of ODEON's impulse responses, even though the system is not calibrated to an absolute Sound Pressure Level. However, it is essential to use the **same measurement equipment and settings consistently** throughout the entire measurement session.

Import/export data from spreadsheets



Data obtained from other applications or tools can be imported as an Excel file that needs to follow the provided template, **available in the ODEON measurements folder** and on our homepage.

Import an entire Excel file

To import a full Excel file, open the Building Acoustics context-sensitive menu and select Load Excel File. Choose your Excel file. This will import all sections of your Excel file at once. Please make sure to keep the template intact, as ODEON relies on its structure. The program will attempt to detect any faults in the imported sections and display warnings if inconsistencies are found.

Note: This operation works with many spreadsheet formats (.xls, .xlsx, .csv etc.) but it requires that the MS Excel application is installed on the PC.

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Copy-paste data from clipboard

You may also copy and paste data in parts from any spreadsheet application—not only Excel. It is recommended to select entire rows to ensure that all 1/3-octave bands are included. ODEON will automatically retain all columns required in the interface.

- Select the rows you want to copy in the spreadsheet.
- Press CTRL+C or Right-click>Copy in the spreadsheet application.
- Click on the relevant section in the interface (eg. Source Room Level (dB)).
- Choose Paste from clipboard from the Building Acoustics context-sensitive menu or press CTRL+V.

Warnings

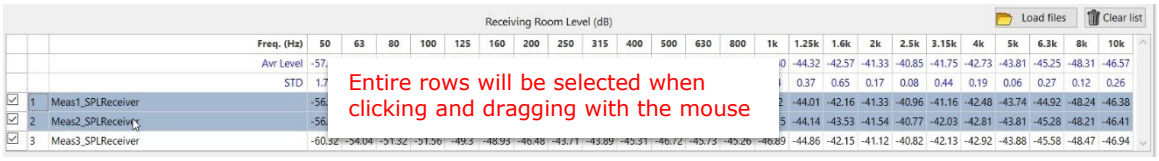
At the bottom of the interface, two types of warnings are presented, which lead to highlighted cells in the tables when they occur:

- **Full Octave Correlation coefficient > 10:** When loading any impulse response in ODEON, the correlation coefficient (XI value) is calculated for each full octave band. Values higher than 10 indicate a highly nonlinear decay curve and should be evaluated further. In the Building acoustics module, any 1/3 Octave band that belongs to a 1/1 Octave band with correlation coefficient higher than 10 will be highlighted. You can monitor the 1/1 Octave band values by looking at the XI parameter of T_{20} or T_{30} at the corresponding loaded impulse response files.
  Note: The warning is indicated only for XI of T_{20} or T_{30}. For any other reverberation time value selected in the interface (such as T_{10} or T_{15}) the XI value for T_{20} is used.
- **Invalid values:** Any values that have not been derived during the loading of impulse responses or during importing an Excel sheet will be indicated by the invalid values colour. This includes negative reverberation times, infinite values, non-numerical characters etc.

Export data to spreadsheets and text files

You may copy any data from the Building Acoustics interface, using the Copy to Clipboard (CTRL+C) function (available from the Building Acoustics context-sensitive menu).

- Press and hold the left mouse button to select the rows you wish to copy from any section in the tables. ODEON will always select entire rows.
- Paste the copied data directly into your spreadsheet application by pressing CTRL+V or Right-click>Paste.



Similarly, you can copy the graphics from the **Reduction index graphs** tabsheet by using the same Copy to Clipboard function or the CTRL+C shortcut.

Export a text file (ASCII Output)

From the Building Acoustics context-sensitive menu, select ASCII Output, or press CTRL+A to export the entire worksheet as a tab-separated .txt file. The exported data can then be copied and pasted into any spreadsheet application while preserving all rows and columns.

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15.3 Calculation example

To demonstrate how the Buidling acoustics interface works, we can perform an evaluation through an ODEON simulation. We can first make use of the *Transmission algorithm* as described in Appendix B, in order to derive the sound levels and the reverberation time (RT) based on a known partition Reduction index. Then we can insert the simulated levels and RT into the Building acoustics interface to calculate the Reduction index and compare to its original values.

The simulation must be performed for many source-receiver combinations to obtain a reliable average of levels and RT. Depending on how reliable are the results, you could consider increasing the scattering coefficient to increase diffuseness and fit better the formula. The room used is as shown below with a partition wall of $S = 20\ m^2$, which has the transmission coefficients shown in Table 15-1. All surfaces are assigned a concrete material No. 103. The receiver room has a volume of $V_R = 100\ m^3$.

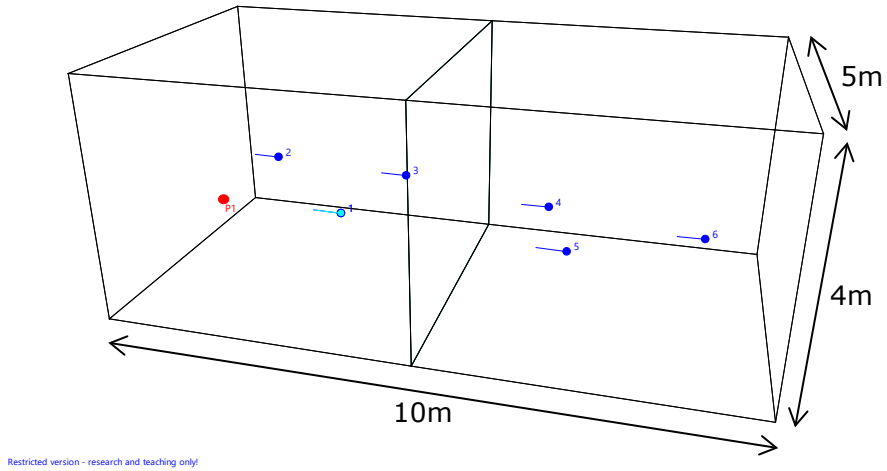


Table 15-1: Theoretical Reduction Index for the partition wall in the ODEON simulation.

Freq.	63	125	250	500	1000	2000	4000	8000
R(dB)	12	10	14	16	18	14	18	22

All simulations have been performed already and the impulse responses for all source-receiver combinations are available at the folder Measurements>Building Acoustics inside ODEON's main installation folder.

Note: For this exercise, the available impulse responses have not been measured, but simulated in ODEON. This means that they have been artificially converted from Energy into Pressure impulse responses and have been denormalized. Normally you should use only measured impulse responses, following the procedure described in ISO 10140 (ISO 10140-2, 2010) and (ISO 10140-4, 2010).

To proceed:

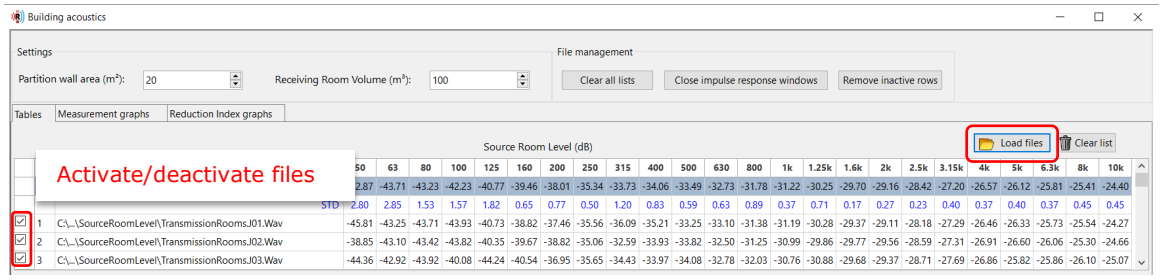
- Open the Building Acoustics interface by clicking Tools>Buidling Acoustics.
- Set the partition wall area to 20 m² and the receiving room volume to 100 m³.

Load the source room SPL files

Click the Load files button in the *Source Room Level (dB)* section and select all files at once from the folder Measurements>Building Acoustics>SourceRoomLevel. Use the SHIFT or CTRL keys for multiple selection.

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The files will be loaded on the first table as in the following screenshot. The average and the standard deviation (STD) values will be calculated automatically. You may use the checkboxes on the left to deactivate specific files, without removing them from the list. The calculation of the average and STD will be updated. To remove inactive files completely, click the Remove inactive files button.

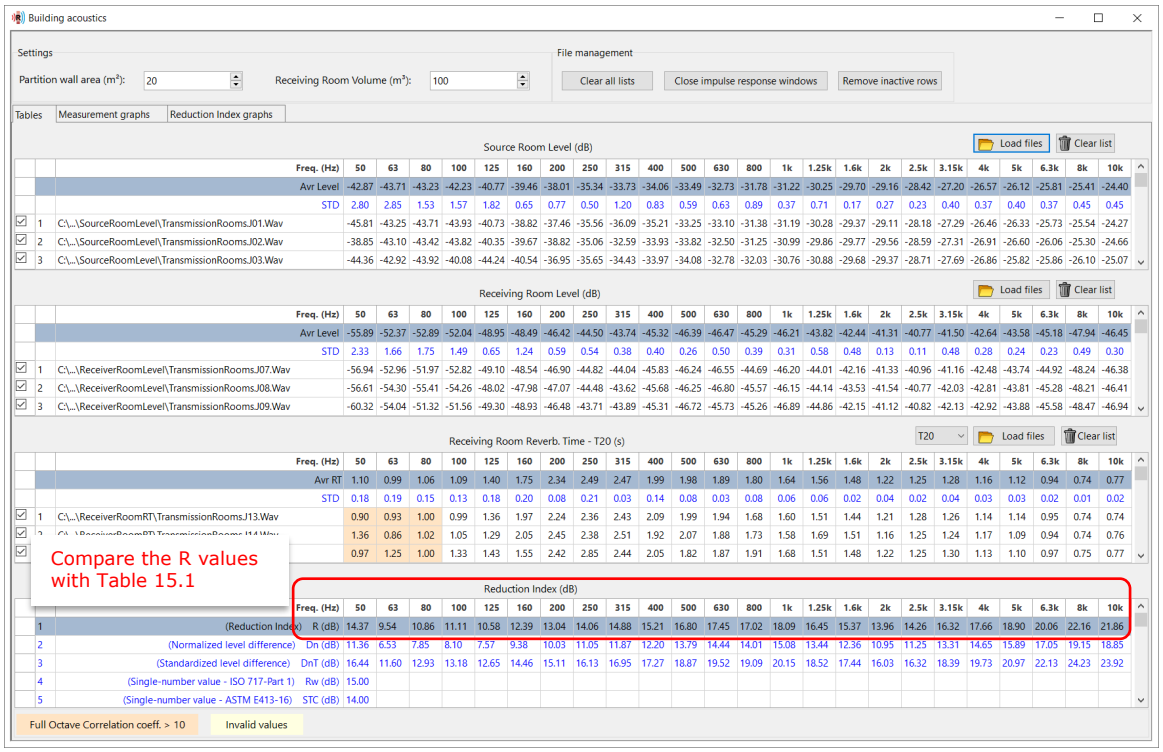


Load the receiver room SPL files

Similarly, load the SPL files for the receiving room by clicking the Load Receiving room files (SPL) button and selecting all files from the folder Measurements>BuildingAcoustics>ReceivingRoomLevel. Use the SHIFT or CTRL keys for multiple selection.

Load the receiving room RT files

Finally, click the button Load Receiving room files (RT) to load the files for the reverberation time in the receiving room from the folder Measurements>BuildingAcoustics>ReceivingRoomRT.
Once this group of files is loaded too, the Reduction Index R and the normalized Reduction Index NR are calculated automatically and shown in the last table. The complete interface with all the files loaded is shown below.



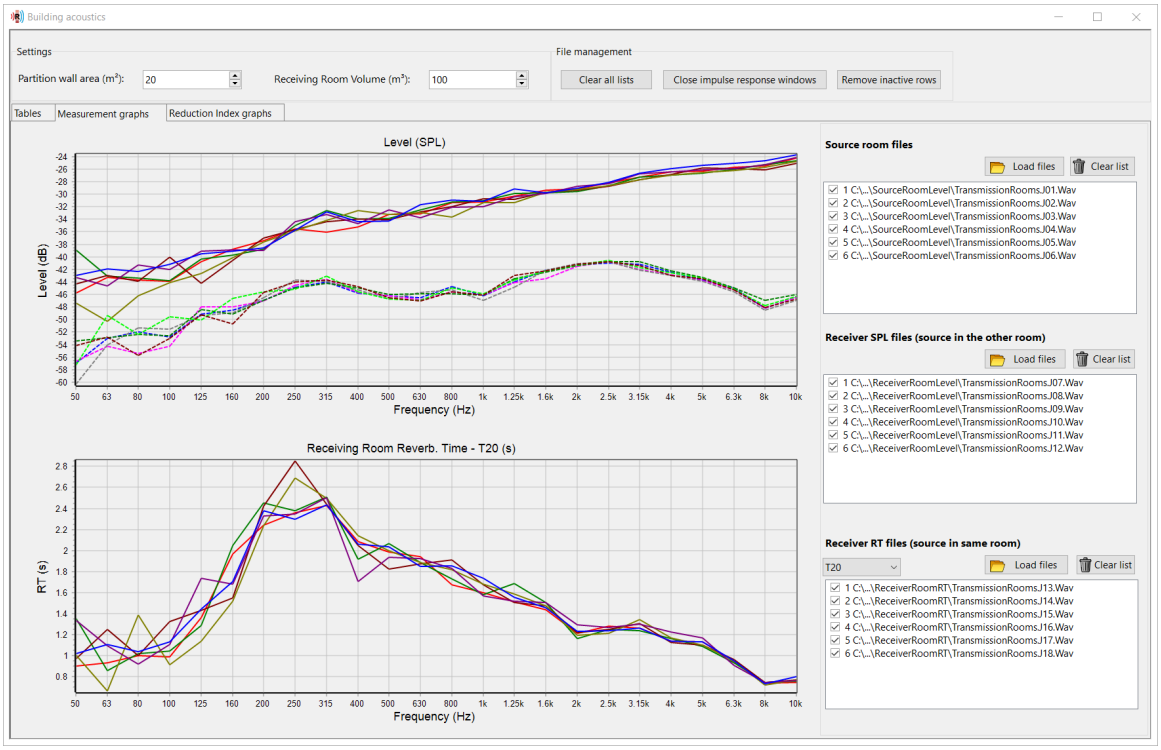
We can now compare the Reduction Index values from the interface to the initial values of Table 15-1. Ideally, these should be identical. However, there are small deviations due to the assumptions involved in the process:

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- The Reduction Index calculation from measurements is based on a diffuse field assumption according to Eq. 15-1, which can be different in an ordinary shaped room.
- There are inaccuracies involved in the processing of the simulated impulse responses. The impulse responses are first simulated in energy domain and then converted to pressure domain using random phase.
- The are inherent inaccuracies at low frequencies because of lack of phase information during simulation in the energy domain.

Despite the aforementioned assumptions, there is still a very good agreement for frequencies 125 Hz and above.
Any change of files in the tables will be reflected directly in the calculated reduction indexes at the lowest table.

The *Graphs* tab sheet shows the values from the loaded files graphically. The graphs are a good tool to check if there are any obvious mistakes in the files. Files can be activated/deactivated from the checkboxes with the changes affecting the tables and results directly.



15.4 Load and export parameters

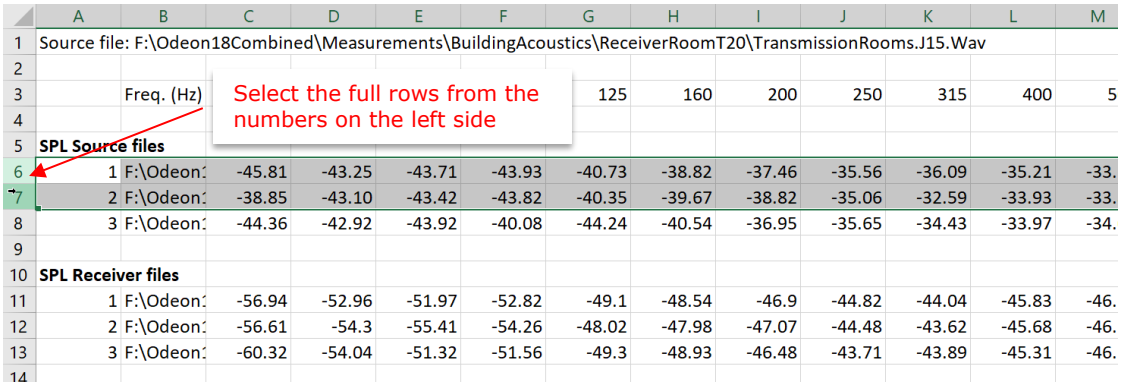
In case you have used an external device for your building acoustic measurements, it is possible to load the SPL and RT parameters in different ways.

Direct copy-paste from excel

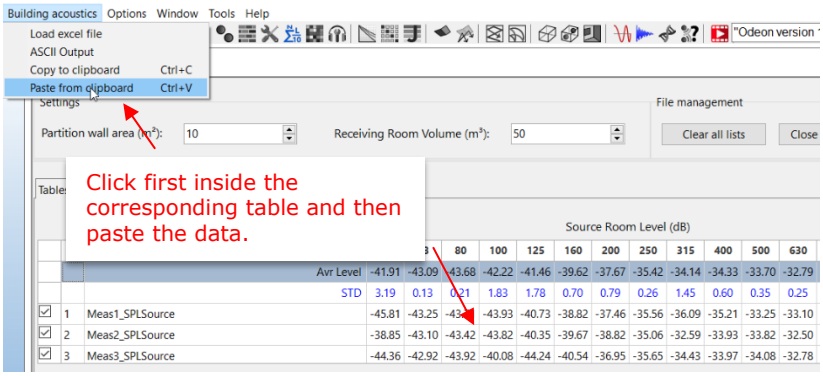
The template supplied with ODEON has to be followed precisely. However, you can add as many rows as you like for each type of measurement. You can also leave several columns that correspond to the 1/3 octave bands empty. They will be simply omitted in the calculation.

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- You should copy-paste each block of measurements separately (SPL at source room, SPL at receiver room and RT at receiver room).
- Select the full rows of one or more measurements. It is recommended to **put your cursor at the left most side in you excel sheet** to ensure that you select the full row. It doesn't matter if all the columns in each row are selected. ODEON will include only the columns up to 10k Hz. Press CTRL+C or select Right-click>Copy.



- Click at any cell inside the table where you want to paste the data (Source Room SPL (dB), Receiver Room SPL (dB), etc.).
- Press CTRL+V or select Building Acoustics>Paste from clipboard from the context-sensitive menu on the main toolbar. In the example above we are inserting the 'Source Room SPL' measurements.

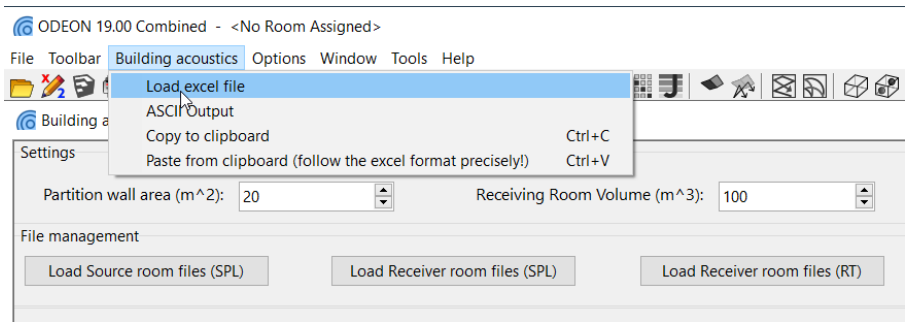


- You can add more rows in the same table, by following the previous steps or by loading impulse responses using the Load buttons - e.g. Load Source room files (SPL) - as in Sec. 15.3.

Once all three tables are completed, ODEON will automatically calculate the transmission indexes.

Load a complete excel file

You may load the full Excel template by choosing Building acoustics > Load excel file from the context-sensitive menu on the main menu bar.

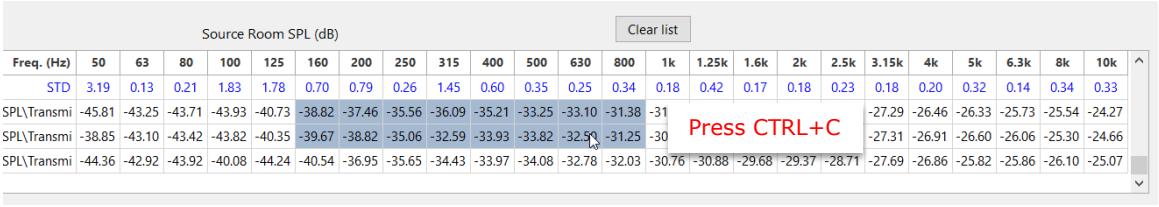


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Export data

Again, from the context-sensitive menu choose Building acoustics > ASCII Output to export all parameters and calculations to a single .txt file. Afterwards, like with all ASCII exports in ODEON, you can select all data in the .txt file and Copy-Paste into Excel. All rows and columns will be preserved.

Data can also be *selected* and *pasted* directly to a spreadsheet or any other text processor (eg. Notepad) from any place in the tables. Click and drag with your mouse to select specific cells and press CTRL+C to copy to clipboard. You can then paste the selected data into Excel or another program.



Freq. (Hz)	50	63	80	100	125	160	200	250	315	400	500	630	800	1k	1.25k	1.6k	2k	2.5k	3.15k	4k	5k	6.3k	8k	10k
STD	3.19	0.13	0.21	1.83	1.78	0.70	0.79	0.26	1.45	0.60	0.35	0.25	0.34	0.18	0.42	0.17	0.18	0.23	0.18	0.20	0.32	0.14	0.34	0.33
SPL\Transmi	-45.81	-43.25	-43.71	-43.93	-40.73	-38.82	-37.46	-35.56	-36.09	-35.21	-33.25	-33.10	-31.38	-31					-27.29	-26.46	-26.33	-25.73	-25.54	-24.27
SPL\Transmi	-38.85	-43.10	-43.42	-43.82	-40.35	-39.67	-38.82	-35.06	-32.59	-33.93	-33.82	-32.50	-31.25	-30					-27.31	-26.91	-26.60	-26.06	-25.30	-24.66
SPL\Transmi	-44.36	-42.92	-43.92	-40.08	-44.24	-40.54	-36.95	-35.65	-34.43	-33.97	-34.08	-32.78	-32.03	-30.76	-30.88	-29.68	-29.37	-28.71	-27.69	-26.86	-25.82	-25.86	-26.10	-25.07

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16 Line Array Sources

(Auditorium and Combined editions only)

This chapter gives an introduction to the use of the line array option in ODEON. The examples are chosen in order to demonstrate some basic properties of line arrays, and they are not representing recommended solutions. It is a delicate process to adjust and optimize a line arrays sound system for a particular room, and the knowhow and technique needed for that is beyond the scope of this manual.

16.1 Stacking the units

By stacking a number of loudspeaker units on a vertical line with a constant distance d between the centres of the units, the first thing to note is that the splay angle changes. The sound is radiated in a more or less concentrated beam, and the splay angle narrows in when the array gets longer. With N units the length of the array is $L = d\ (N\text{-}1)$, and this should be longer than one wavelength in order to obtain the narrowing of the splay angle. This can be expressed by a lower limiting frequency:

$$f_l = \frac{c}{L} = \frac{c}{d(N-1)}$$

where $c = 344$ m/s is the speed of sound. However, the concentration into a single beam only works at frequencies below the upper limiting frequency, i.e. when the distance between the units is short compared to one wavelength:

$$f_u = \frac{c}{d}$$

Above f_u the sound radiation breaks up into a number of directions. The near field radiation at 1 kHz is shown in Fig. 14-1, with different number of units in the array, from 1 to 11. The unit in the example is SLS_LS8800.CF2 imported from the CLF collection of loudspeakers and the distance between units is $d = 20$cm. Whereas the single loudspeaker unit spreads the sound in a wide fan, the level decreases rapidly with distance. With increasing number of units in the array the sound gradually concentrates in a beam with very small splay angle.

The sound radiation in the octave bands from 250 Hz to 8 kHz with 7 units is shown in Figure. 14-2.

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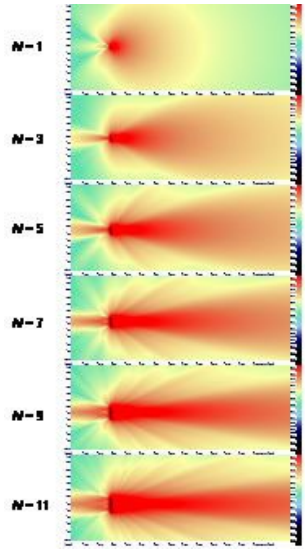


Figure 16-1. The radiation at 1 kHz from arrays with increasing number of units, from a single unit to 11 units (1, 3, 5, 7, 9 and 11).

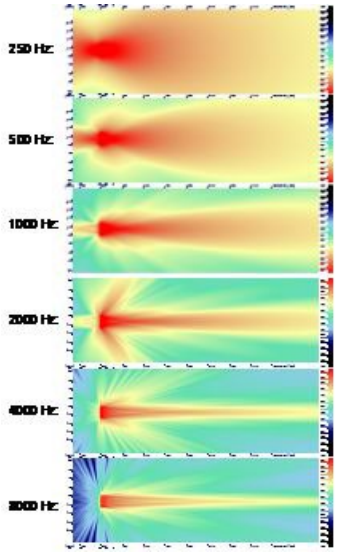


Figure 16-2. The radiation in octave bands from 250 Hz to 8 kHz for a line array with 7 units.

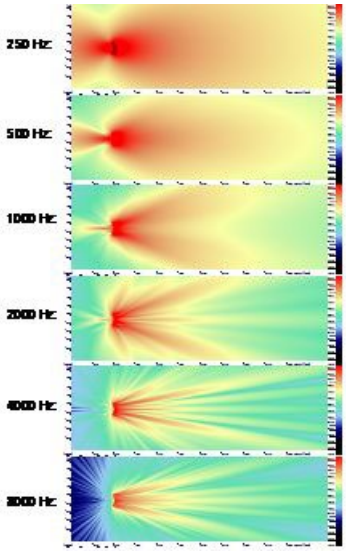


Figure 16-3. Similar to Figure 10-2, but the array is bent, see Table 1.

In order to increase the splay angle to fit an audience area, it is usual to apply different elevation angles to the units, and thus creating a bent array. An example is shown in Figure 14-3 and the coordinates and elevation angles of the units are shown in Table 14-1. At high frequencies it is obviously a problem in this example that the sound radiation splits according to the number of units and there are gaps with poor sound radiation.

Table 16-1. Coordinates and elevation angles of the 7 units in the array example in Figure 10-3.

Transducer	x	y	z	Elevation
1	0.000	0.000	0.000	15
2	0.100	0.000	-0.200	10
3	0.150	0.000	-0.400	5
4	0.200	0.000	-0.600	0
5	0.150	0.000	-0.800	-5
6	0.100	0.000	-1.000	-10
7	0.000	0.000	-1.200	-15

16.2 Playing with delay

One advantage of the line array is the possibility to control the direction of the main lobe of sound by means of small phase shifts, different for each of the units. So, instead of physically tilting the loudspeaker the line array can be mounted in a vertical position and still **direct** the sound towards the audience.

If the units all have the same distance d and the delay from one unit to the next is Δt, the angle of sound radiation relative to the normal direction perpendicular to the array line is:

$$\theta = \mathrm{Arctg}\left(\frac{c \cdot \Delta t}{d}\right)$$

Figure 14-4 shows an example with Δt = 0.1 ms per unit. Figure 14-5 the same with Δt = 0.2 ms per unit.

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Note: In order to turn the beam downwards the delays should be set from 0 ms in the upper unit to $(N\text{-}1)\Delta t$ ms in the lower unit, e.g. 1.2 ms in the case of $N = 7$ and $\Delta t = 0{,}2$ms.

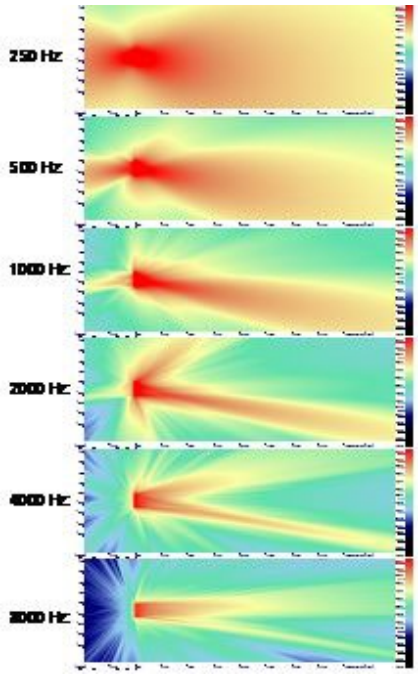


Figure 16-4. The radiation in octave bands from 250 Hz to 8 kHz for a line array with 7 units and a time delay 0.1 Δms per unit.

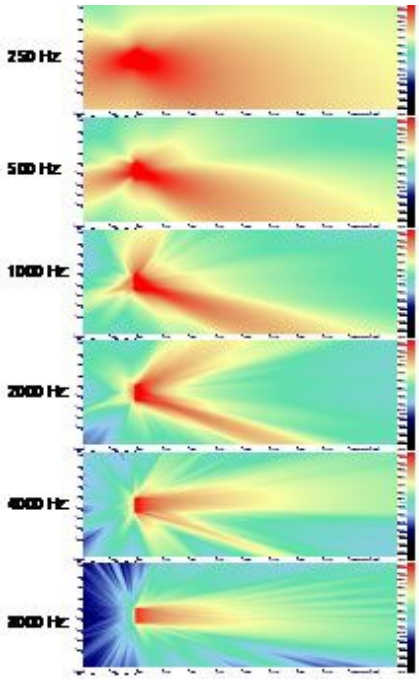


Figure 16-5. Same as Figure 14-4, but with a time delay 0.2 Δms per unit.

At the 2 kHz band and higher frequencies (i.e. above the upper limiting frequency, 1720 Hz in this example) a rather strong side lobe of radiation is seen at various directions slightly upwards. This is the effect of the units being more than one wavelength apart from each other. If the phase is shifted by one period, another angle of radiation is found. Geometrically, the angles that correspond to i periods phase shift can be calculated from:

$$\theta_i = \mathrm{Arctg}\left(\frac{c \cdot \Delta t + i \cdot c / f}{d}\right)$$

where f is the frequency and $i = \pm 1, \pm 2$, etc.
The theoretical angles of radiation corresponding to this example are shown as a function of the frequency in Table 14-2. The direction of the main lobe relative to the horizontal direction is 10° for $\Delta t = 0.1$ ms and 19° $\Delta t = 0.2$ ms. The results for $i = -1$ explain the upward side lobes seen at 2 and 4 kHz in Figures 14-4 and 14-5.

Table 16-2. Calculated angles of radiation from the example array with $d = 0.20$ m. Positive angles are downwards and negative angles are upwards. Calculated for two different values of the delay per unit, Δt.

Δt	0,1 ms			Δt	0,2 ms		
i	0	-1	1	i	0	-1	1
f (Hz)	θ	θ_{-1}	θ_1	f (Hz)	θ	θ_{-1}	θ_1
125	10	-86	86	125	19	-86	86
250	10	-82	82	250	19	-81	82
500	10	-73	75	500	19	-72	75
1000	10	-57	62	1000	19	-54	64
2000	10	-35	46	2000	19	-27	50

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4000	10	-14	31	4000	19	-5	38
8000	10	-2	21	8000	19	7	29

Delays for individual transducers in a line array should not be confused with the overall delay assigned to one point source or array source of many in a room in order to benefit from the Haas effect, although the devices used in order to obtain the delays may be identical:

- Different delays assigned to individual transducers in a single line array have the purpose of achieving the effects described in this section, with the assumption that the individual transducers are close to each other and periodically spaced.
- For the Haas effect, on the other hand, more than one loudspeaker in the room is required, and delays are mainly applied a whole loudspeaker (in the case of an array, the same delay is applied to all of its transducers). The assumption is that the loudspeakers are sufficiently far away from each other.

Example:

If transducer 1 is delayed by 0 ms and transducer 2 is delayed by 3 ms, then at t = 3 ms transducer 2 emits the same signal value as transducer 1 emitted at t = 0.

16.3 Playing with level

If the level is not the same for all the units in the array, but it increases gradually from bottom to top, the beam of radiation becomes asymmetric. An example is shown in Figure 14-6 with a level increase of 2 dB per unit.

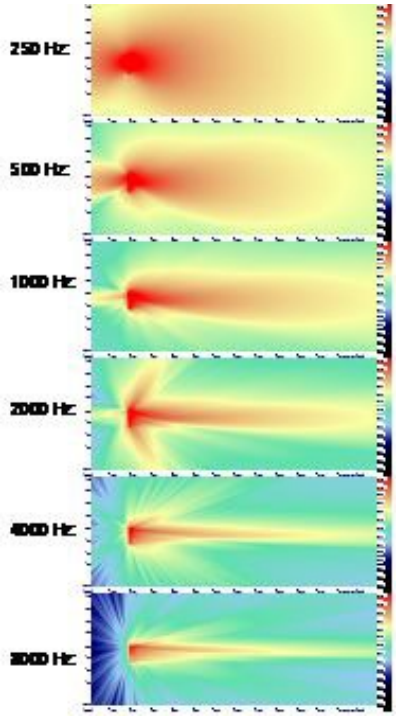


Figure 16-6. The radiation in octave bands from 250 Hz to 8 kHz for a line array with 7 units. The level increases by 2 dB per unit from bottom to top.

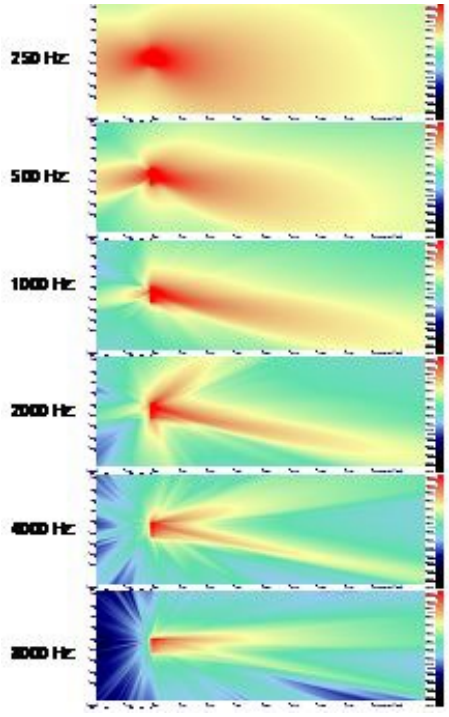


Figure 16-7. The radiation in octave bands from 250 Hz to 8 kHz for a line array with 7 units. The time delay is 0.1 ms per unit and the level increases by 2 dB per unit from bottom to top.

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16.4 Combining delay and level adjustments

With the combination of delay and level adjustments it is possible to design a sound radiation that is asymmetric and directed off the horizontal axis, see the example in Fig. 14-7. This can be used to create a very uniform sound level over an extended audience area.

16.5 Using the equalizer

In addition to the general equalizer for the array, there are equalizer options for each transducer. This may be used for fine adjustments or to turn off some transducers at some frequencies. E.g. if you want to use a shorter array at the high frequencies, you can enter a high attenuation of the transducers in question.

16.6 Bringing the array into the room

The position of a line source in a room is similar to that for a simple point source, but with some extra options:

- If the transducer coordinate system is **Absolute** it means that the x, y, z, coordinates of the array indicate the position of the transducer with relative coordinates (0, 0, 0), if any (there doesn't need be a transducer in this position, but all transducer coordinates are relative to this point).
- If the transducer coordinate system is **Relative hanging** it means that the x, y, z, coordinates of the array indicate the position of the transducer in the *top* of the array, and the coordinates of the other transducers are relative to this.
- If the transducer coordinate system is **Relative standing** it means that the x, y, z, coordinates of the array indicate the position of the transducer in the *bottom* of the array, and the coordinates of the other transducers are relative to this.
- In all three cases it is possible to include an additional offset of the coordinate system. For example, this can be used with the relative standing position to specify the distance from the centre of the lowest transducer to the physical bottom of the array loudspeaker.

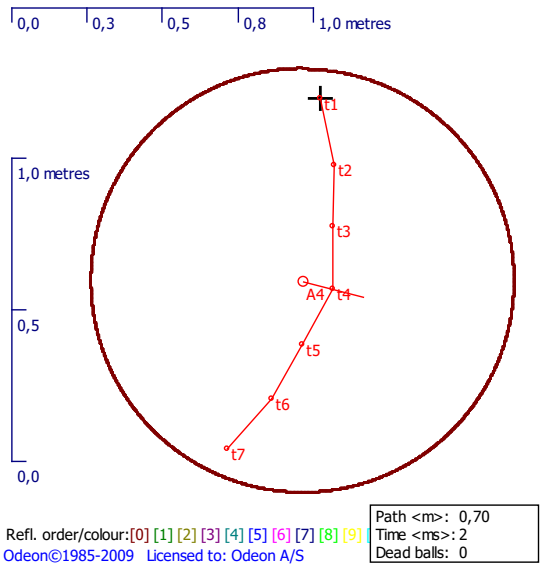


Figure 16-8. An array source with 7 units (as specified in Table 14-1). The ray tracing in the room acoustic simulations is made from the acoustical centre, shown just behind unit T4. The coordinates defining the position of the array refers to the cross on top of the array.

The direction of the array is controlled from the acoustic centre of the array, Figure 14-8. It may be convenient to define a receiver point to be the aiming point, or the 3D Render option will let you look into the room from the centre of the array and the aiming point is the centre of the picture (the crossing point of the two diagonals will indicate the exact point).

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Appendix A: Vocabulary

The techniques of auralisation make use of many of technologies, and a lot of technical terms and abbreviations are commonly used in the literature. Here is a short vocabulary to some of the most used expressions - the vocabulary is not a complete description of the individual words - the context under which the words are used are many and the subjects are rather complex.

Anechoic recording

Anechoic recordings are recordings of sound sources made without any reflections from the surroundings contributing to the recordings. A common problem with anechoic recordings is that they may often include too many high frequency components, because they are usually near field recordings and because they are recorded 'on axis' where these components usually dominate. When using such recordings with auralisation systems this may often result in unrealistic sharp 's'-sounds especially in case of long reverberation times. Anechoic recordings are usually recorded in an anechoic room, but semi-anechoic recordings may also be acceptable for use with auralisation systems, this could be outdoor recordings of machinery, trains etc. or studio recordings of music.

Auralisation, auralization

The term auralisation was invented by Mendel Kleiner who gives the following definition: “Auralisation is the process of rendering audible, by physical or mathematical modelling, the sound field of a source in a space, in such a way as to simulate the binaural listening experience at a given position in the modelled space.”

When used in ODEON, one may think of auralisation as the art of creating digital simulations of recordings in rooms (which may not even be built yet). The aim is to provide the same three-dimensional listening experience to the listener as would be achieved in the real room at the given receiver position with the simulated source position(s) and signals.

Binaural (recording)

Humans (usually) listen using two ears. This allows us to perceive sound as a 3D phenomenon. To create a binaural recording, it is not enough to create a two-channel recording (stereo), since also the effect of diffraction from the human body on sound has to be included. This is usually done by using a dummy head with a microphone mounted at the entrance of each ear canal - this recording may be recorded using an ordinary stereo recorder - but is now referred to as binaural. Binaural recordings are usually played back through headphones to avoid room effects on the played sound, as well as avoiding diffraction from the human body to be included twice (once in the recording and additionally during playback). If one has measured or indeed simulated the BRIR's (see below) in a room, it is possible to 'simulate' a binaural recording.

BRIR – Binaural Room Impulse Response

The BRIR is the key to binaural room acoustic auralisation. The BRIR is a set of impulse responses detected at the left and right entrance of the ear canals of a dummy head, or indeed at blocked entrenches of the ear canals of a (living) person residing in a room, when a sound source (or some sound sources) has emitted an impulse. The BRIR should include all the (necessary) information on receiver position and orientations, source position(s) and orientation(s), room geometry, surface

materials and the listener's geometry (described by the HRTFs). Convolving the left channel of the BRIR and the right channel of the BRIR with a mono signal, a binaural signal is created, which when presented to the listener over headphones gives the impression of the three-dimensional acoustics at a particular position in the room. It is also possible to simulate the recording of the BRIR's, which ODEON is able to do.

DIRAC

The Dirac delta function (often called a Dirac or Dirac function) was introduced by the physicist Paul Dirac. In room acoustics, it is used for defining a reflection which has a value of 1 at the time of the reflection (in an infinitely short interval – thus the delta). This Dirac is them multiplied by the actual strength of the reflection e.g. in a given octave band.

Dither

Dither improves the quality of audio containing harmonic signals (not impulse responses) when storing the signals in an integer format. Audio signals are normally saved in 16-bit integer format which is more compact than 'standard' 32-bit floating-point data and better supported playback software (and it's the format on audio CD's). This means that software like Odeon has to quantize the floating-point signals which are results of calculations into integer values (e.g. 16.35345 becomes 16 etc.) by doing this a difference between what the signal sound have been and what it is become occurs and this difference can be quite audible and sound bad for harmonic signals (having sinusoidal shapes in them). Dither is a smart technique to overcome this problem. By adding a weak noise signal to the original floating-point signal before performing the quantization the audible artefacts are reduced. As strange as it may sounds adding a noise signal reduces noise and distortion introduced by the quantization. Still adding noise to your audio signal sounds undesirable right! That's were noise shaping comes into play, by applying a desired spectrum to the dither noise it possible to put the dither noise at frequencies where we know humans are not very sensitive to sound namely at very high and low frequencies.
If Apply dither and noise shaping is enabled in the Auralisation setup in Odeon then Odeon will apply dithering to convolved output signals which may contain harmonics. Dithering is never applied to impulse responses (and is not used at all if Wave result file is set to a floating-point format in the Auralisation setup. Odeon applies a dither signal with values between +/-1 with a triangular distribution.

HRTF's – Head Related Transfer Functions

The HRTF describes how an impulse arriving at a person /dummy head is smeared out by diffraction phenomena from head and torso of the 'person'. While an incoming impulse is only 1 sample long, this will result in an impulse response arriving at the right and an impulse response arriving at the left ear, which may typically have a length (of interest) of some 2 -3 milliseconds (approximately 100 samples at a 44100 Hz sample rate, or if you prefer a length of 1 metre or so) - this is what is described by the HRTF's. A set of HRTF's used for auralisation will typically contain a library for many different angles of incidence. The HRTF's that come with ODEON are those made available by the CIPIC Interface Laboratory at http://interface.cipic.ucdavis.edu/index.htm as well as those from by Bill Gardner and Keith Martin at MIT Media Lab. at http://sound.media.mit.edu/KEMAR.html. HRTF's will be slightly different depending on the specific shape of a person's body, so if possible, it would be optimal to measure and use an HRTF measured for a specific person. Then, the auralisation would turn out very accurate for that person. Though, one should keep in mind that measuring someone's HRTF requires special equipment and may be a tedious and costly process. If you have the capability of measuring HRTF's it is possible to import new sets for use with ODEON. To compensate for the fact that you'll typically not use

your own HRTF's in the auralisation process and that many different people may indeed listen to the same auralisation, Odeon can enhance the directional cues in the HRTF's and does so by default. This process involves enhancing some of the spectral differences in the HRTF while ensuring that the overall process doesn't spectrum the auralisation output too much. The result is typically better externalisation (out of head experience) and better localisation.

Noise shaping

See dither.

Scattering Coefficient

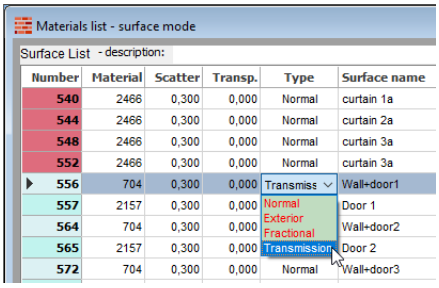
It has values from 0 to 1. Defines the portion of energy that is reflected in a diffuse manner from a surface. The rest of the energy is assumed to be reflected in a pure specular manner.

Appendix B: Specify Transmission Though Walls

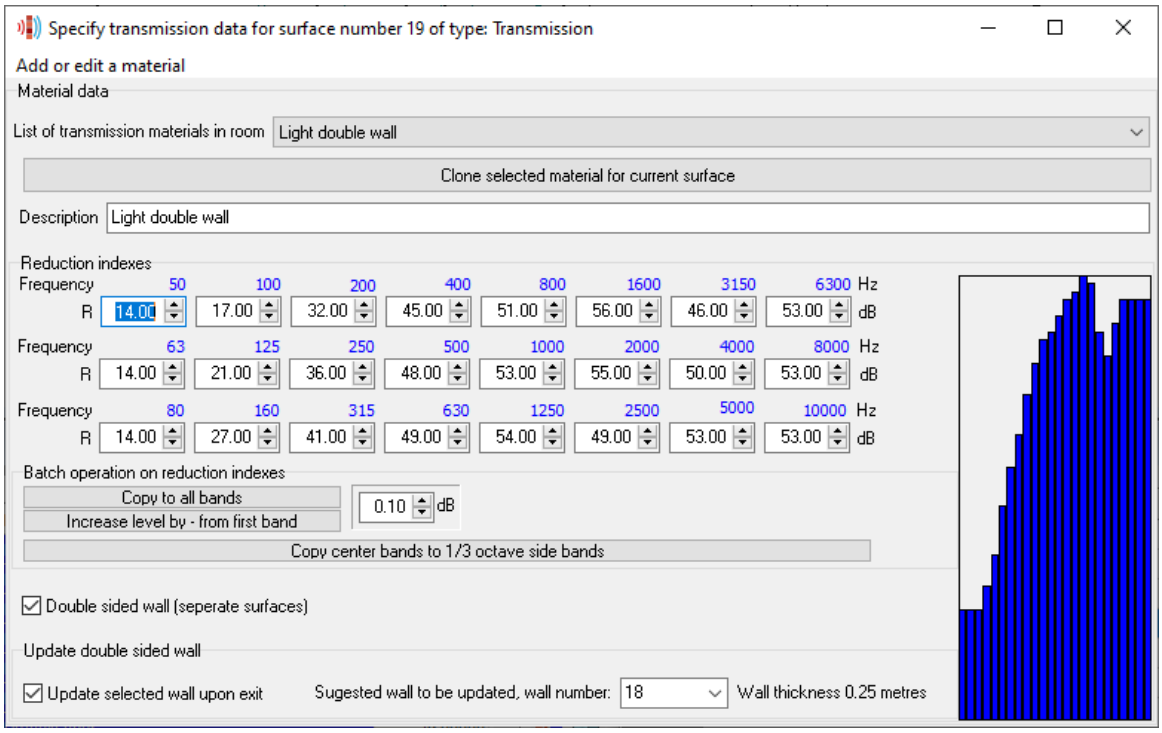
Since ODEON 9 transmission through walls can be simulated, taking into account multiple transmission paths, allowing walls to have a thickness and to have different materials on either side of the transmission wall. Any transmission properties work completely independently from absorption. This means that you shouldn't expect a material to absorb more sound because it has transmission properties.

For any transmission calculation in ODEON, only 10% of the rays are let pass through a wall, while the remaining 90% are kept inside the source room for simulation of room acoustics. Compensation is made concerning the energy, so the calculation result in the source room is not affected by some rays being transmitted to another room – only the absorption data for the wall is used. In general, it is a good practice to use a higher number of rays (e.g. double the amount) when making transmission calculations to ensure enough rays will reach the receiving room (behind the wall).

Assigning transmission data



Once a Type of a wall has been set to Transmission in the Material List, it becomes possible to specify transmission data, using the Edit transmission data for surface (button or Alt+Y shortcut). This opens a dialog where reduction indexes can be specified in one-third octave bands from 50 Hz to 10 kHz. The data can be entered directly or copied from a spreadsheet (or from a text file) using the common shortcuts Ctrl+C and Ctrl+V. For an example of transmission, open the room Transmission rooms in the ODEON Rooms folder.



In the Specify transmission data interface you can insert transmission coefficients in dB for 1/3 octave bands. If your data comes only in full octave bands you can insert the full octave band values and copy the data to

1/3 side bands by pressing the Copy center bands to 1/3 octave side bands button. The option Double sided wall allows having the same transmission coefficient for two surfaces of different absorption.

Remember: With the transmission tool, ODEON is able to calculate the transmission of airborne sound through a wall. It cannot calculate the structure-borne sound propagation nor flanking transmission. ODEON requires the transmission properties (coefficients) of the wall as input data – exactly like for absorption coefficients. When a composite structure – such as a sandwich panel - is used in ODEON simulations, the transmission properties shall be obtained externally in four ways:

- By the datasheet from the manufacturer of the structure.
- By measurements.
- By hand calculations, using analytic formulas.
- By using software dedicated for calculating transmission coefficients of different materials (eg. INSUL by Marshall Day Acoustics).

Copying transmission data from Excel

A material to be copied may contain a leading comment/name and must end by 24 floating point values, corresponding to the 24 reduction indexes from 50 Hz to 10000 Hz. The first value is always assumed to be for the 50 Hertz one-third octave band. So if less than 24 values are pasted, the highest bands will be left empty, and if more than 24 values are pasted, the exceeding values are discarded. To copy the values from Excel, mark the relevant cells and press Ctrl+C - to paste the values into Transmission dialog, simply press Ctrl+V. Likewise to copy data from the *Transmission* dialog to Excel press Ctrl+C while the dialog is the selected window in ODEON - then select the first cell in Excel or whichever cell is relevant) and press Ctrl+V. Data can also be imported from Insul Sound Insulation Prediction software (Ins11), simply by copying the spectrum for Bastian format and pasting into ODEON.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	Sound Transmission Loss	50	53	80	100	125	160	200	250	315	400	500	630	8
2	Light double wall	14	14	14	17	21	27	32	36	41	45	48	49	

Copying transmission data of the reduction index from Excel.

A wall with different material on either side and walls modeled with thickness

Sometimes a transmission wall may be composed by two individual surfaces (two separate surfaces in the Materials List) as shown in the illustration from the 3DBilliard display below. It is possible for ODEON to link together such a pair of surfaces if they are (almost) parallel, allowing transmission through walls with different absorption properties on either side. The reduction index itself takes into consideration the wall thickness. So for a wall consisting of two parallel surfaces, the reduction Index should only be used once. To accomplish this, it is important that:

- Transmission type is assigned to both surfaces in the Materials List.
- The same set of reduction indexes is selected on either surface in the Transmission dialog.
- Double sided wall check mark is selected for both surfaces in the Transmission dialog.

Most of the above can usually be accomplished if the *Update double sided wall upon exit* is checked when Transmission data for the first wall is edited. It is recommended checking and rechecking the data entered for transmission data before making calculations, a check may involve using the 3DBilliard or 3D Investigate Rays to ensure that walls do in fact transmit sound and that double-sided walls has been set up correctly.

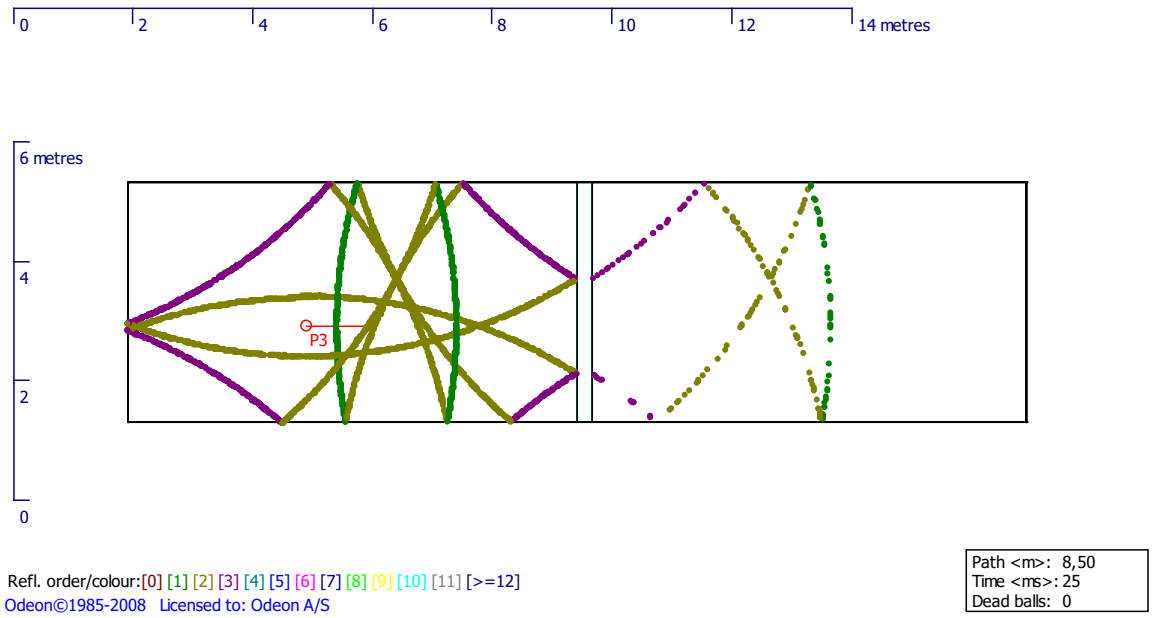
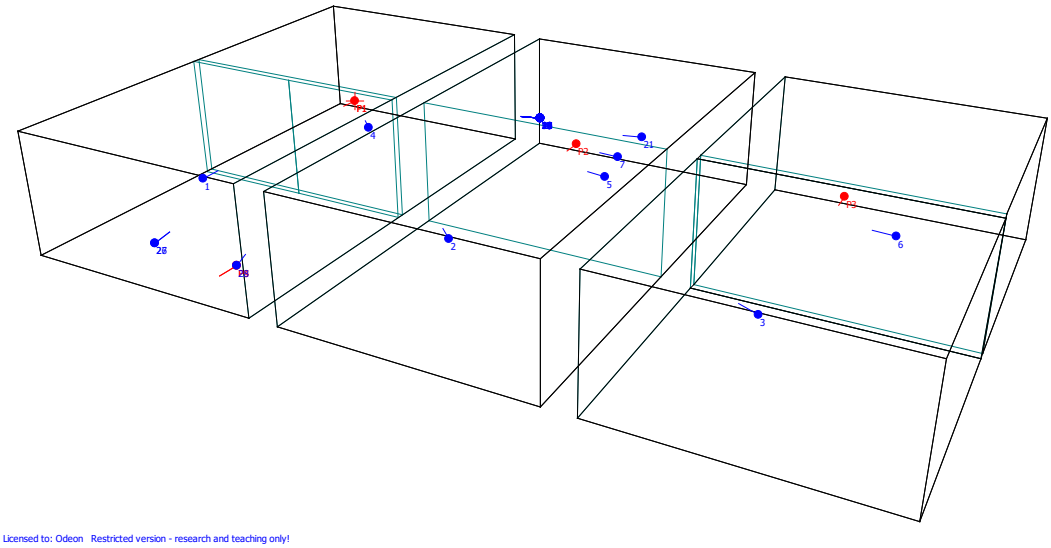


Figure B2: 3DBilliard display illustrating Transmission through a double-sided wall – as can be seen, ODEON understands correctly that balls should jump through the wall, from one surface to another.

The principle of calculations is shown in the figure above. Statistically 10% of the balls (rays) are transmitted and 90% are reflected. However, this is compensated for in the calculations, so the energy losses in the two rooms are determined by the absorption coefficients and reduction indexes, as used.

The Transmission Rooms.par sample is installed with ODEON. This example illustrates how transmission data is assigned to transmission walls, when transmission walls are composed from a single surface, two surfaces and three surfaces. Once the room has been loaded into ODEON, additional information is available in the Notes editor using the Shift+Ctrl+N shortcut. In the JobList, some example setups have been prepared for calculations in source rooms as well as in receiver rooms.



Appendix C: Importing Array Loudspeaker Data (XML format)

The ODEON XML format for array loudspeakers allows importing array parameters, that specify how a number of transducers are combined together to form an array loudspeaker. Arrays can be beam-steered (a digital filter being assigned to each transducer) or a more conventional array where each transducer is fed directly (or through an equalizer, with a delay etc.). External files needed: a directivity pattern for each transducer. Currently the following directivity formats are supported; Common loudspeaker format (.CF1, .CF2) and ODEON's native format .So8.

The frequency range needed by ODEON covers the full octaves from 63 Hz to 8 kHz, however in order to make the format as versatile as possible (e.g. for future use or for use in other programs), frequencies from lower and higher bands can be included – ODEON will just ignore those bands.

XML (e*X*tensible *M*arkup *L*anguage) has been chosen as the format for import of data for arrays loudspeakers, because:

- It's a standard (ISO 8879, 1986). See also *http://www.w3.org/XML/*
- It allows eXtending the data being exported and imported when needed, by adding new attributes to nodes and by adding new nodes.
- Parsers for writing and reading the format are available in most (or all?) modern programming environments.
- Even if a parser is not available to the people exporting data (e.g. Loudspeaker Manufacturer), it is fairly easy to write XML formatted data – the import part which is more complex is left to ODEON (or similar programs).

The layout of the XML file

To understand and learn the format, the XML files installed with ODEON e.g. in the C:\ODEON10Combined\ArrayXML\ should be studied. This manual explains details of the format, but most of the format is best understood from reading through the sample files. The node (or tree) structure of XML files is complicated but best understood by studying the sample files and looking in this manual when **more** details are needed. See the figures on next page to get a picture of the tree structure.

The following XML sample files are installed with ODEON:

Monopol.xml
Dipol.xml
Quadropol.xml
Octopol.xml
Dipol_Domain_Frequency.xml

The names of the first four files are almost self-explanatory, those are the classic textbook examples built from 1, 2, 4 and 8 sources. These sources utilize the Omni.so8 directivity pattern for all their transducers. The four sources are all conventional arrays which have been assembled inside the ODEON Array source editor and exported from there. The only trick is that the Invert phase option has been applied to half of the transducers in the Dipol, Quadropol and Octopol arrays in order to get the special behaviour of those source types. The Dipol_Domain_Frequency.xml file is essentialy identical to the Dipol.xml and will give same results when used inside ODEON, but this file has been defined using Domain=Frequency which is the option that can be used when defining beam-steered arrays.

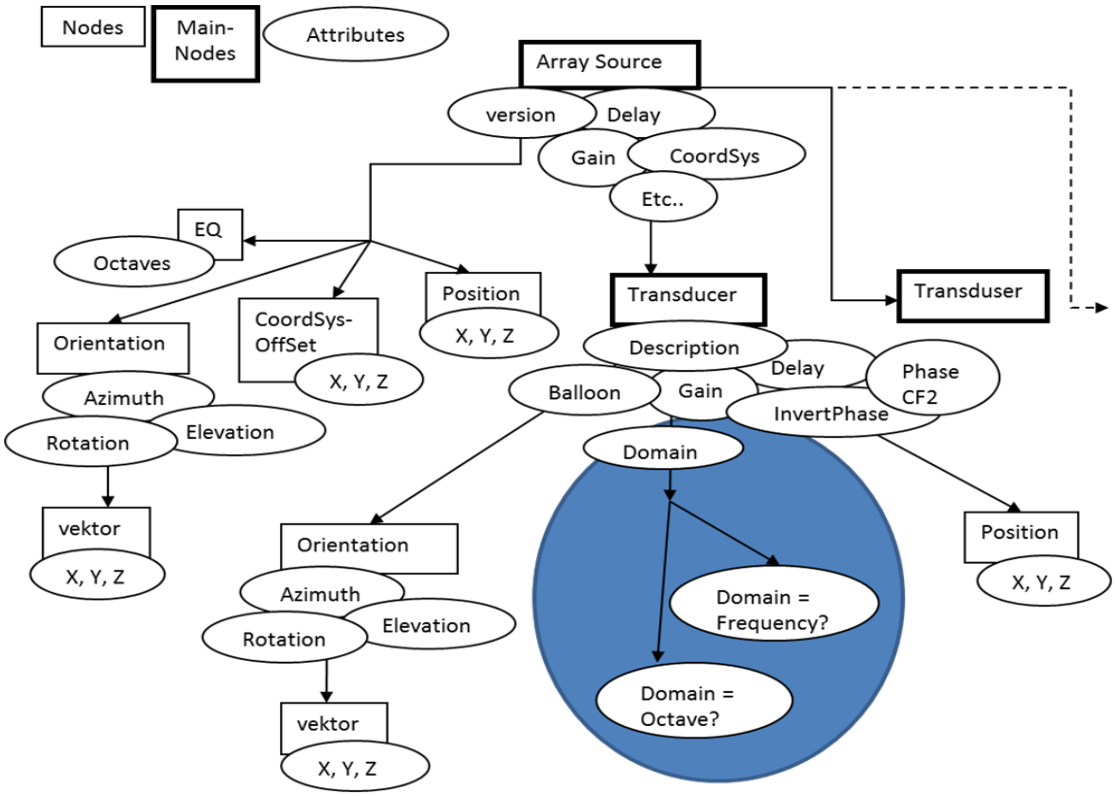


Figure E1: Tree structure for the Array source node - The Domain Data nodes are described separately in figure E2.

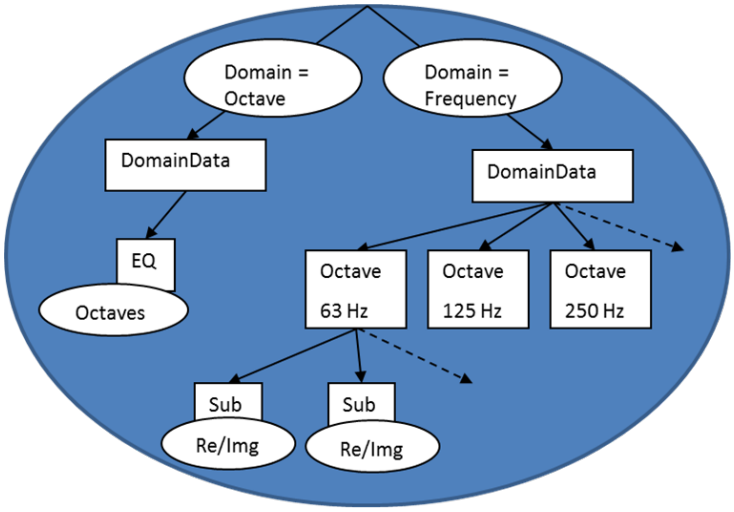
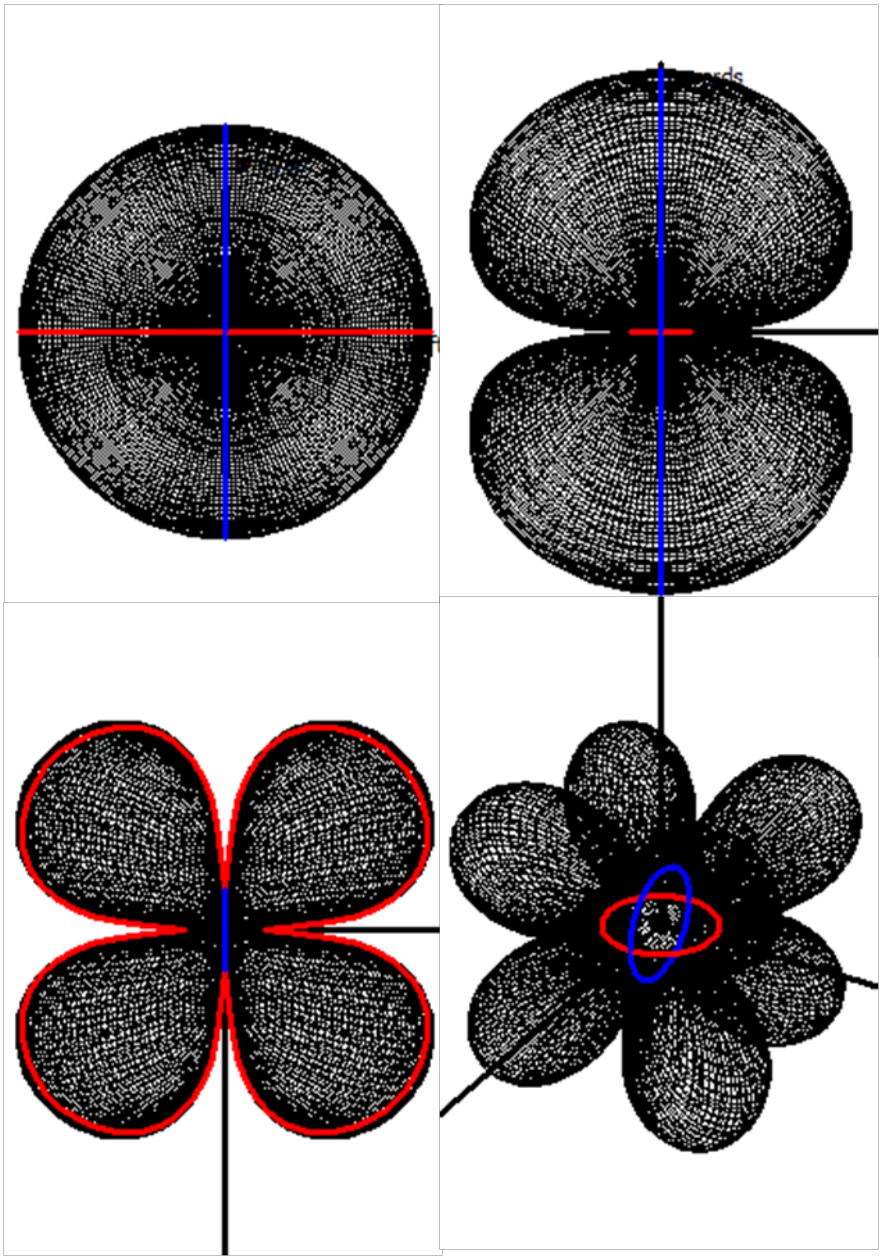
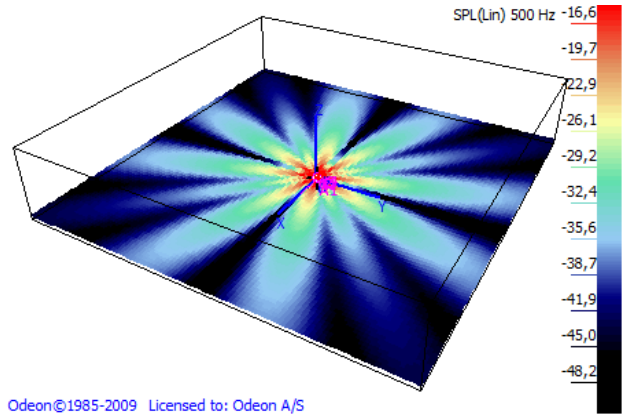


Figure E2: Tree structure with the details of the Domain Data node. This note comes in two versions depending on weather Domain=Octave or Domain=Frequency.

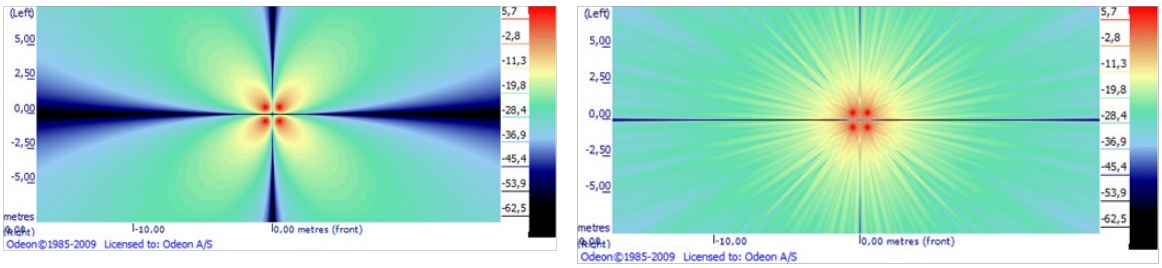


Viewing the sample files in ODEON

The XML files are text files and can be viewed in a text editor such as Notepad or ODEONEdit. Because the sample files follow the format outlined in this description, they may also be viewed in the ODEON Array Source Editor. It is described how to view the files from within the Array Source Editor in the "Testing if XML files…" section below.



Having loaded one of the files into the Array Source Editor, the near field balloon, far field balloon and a 3D_Direct display can be studied. Note that these directivity patterns are strongly frequency dependent and have pronounced symmetry properties; at high frequencies their patterns break down and show strong fluctuations (see figure E4), and viewing an Octopol in the Near field balloon display may not prove interesting because it will never radiate any energy in its symmetry planes, which is what is displayed in this window (horizontal or vertical as selected). On the other hand, the Quadropol in the following figure gives a meaningful display.



The Quadropol sample viewed in the near filed balloon tab in the Array source editor. To the left at 63 Hz, to the right at 4 kHz.

Testing if XML files can be imported correctly into ODEON

The demo version of ODEON (or a full version of ODEON Auditorium or Combined) can be used for this purpose. If you are reading this, you have probably already installed it, if this is not the case, you may download the demo version. To model and view the array in ODEON, you only need to use a very limited number of features – there is no need knowing all features in the ODEON software. In a full version, you may import your array into any room. In the demo version, you should open the ArraySpeakerTestRoom.Par room located in the "Extra Rooms>Appendix-Speaker Array" folder

(e.g. C:\ODEON11Combined\Rooms\Extra Rooms\Appendix – Speaker Array\ArraySpeakerTestRoom.Par).

The ArraySpeakerTestRoom.par room is a large box measuring 100x100x20 metres, by default all surfaces have been assigned 100 % absorbing material as its not intended for room acoustics predictions:

- To load this room, use the File>Open Room menu entry.
- Once loaded, open the Source receiver list (shortcut Shift+Ctrl+S)
- In the Source receiver list, define an array (shortcut A)
- In the Array source editor, import a XML array file (shortcut Ctrl+O)

That's it. Hopefully the array imports without problems, otherwise load it into the ODEONEdit editor to study the XML code. When the file is loaded, you have the chance to study the array in various tabs of the Array source editor.

Viewing and editing XML documents

If your program writes data to be imported into ODEON then we will refer to it as *WRITER*, ODEON on the other hand will be referred to as the *READER (*ODEON will normally be the reader, but being able to export array data, it is a *WRITER* as well).

When developing export facilities for array loudspeaker data you may need to inspect or manually edit the files. XML files can be browsed and edited in simple programs like Notepad, however, the ODEONEdit editor will perform syntax highlighting. The ODEONEdit editor is installed with ODEON 10 or later (including the free demo version).

Decimal point can be either "," or "." in the XML files. ODEON will convert the XML files upon import to conform to the regional settings of the PC on which it's running.
The format is case-sensitive, therefore it is important that Attribute and Node names are spelled with upper and lower case as defined – use one of the examples installed with ODEON (and cut and paste directly from there to your code).

Encoding and formatting of XML documents

Encoding should be set to UTF-8: <?xml version="1.0" encoding="UTF-8"?>, or in a coding environment, XMLDocument.Encoding := 'UTF-8'. Most parsers should be able to read a number of other encodings though. To allow reading the XML document by eye, consider to set XMLDocument.Options := [doNodeAutoIndent], if that option is available in your programming environment.

XML document content

Much of the data given in the XML file is optional. If not given in the XML file, ODEON will set a default value. The nodes and Attributes of the tree-structure is described below and should be compared with the XML-file to keep on track. See also figures E1 and E2 (page 187).

Main node (all nodes below included)
ArraySource – *Main node in the XML file which holds the entire array.*

Attributes to ArraySource

ODEONArrayVersion="10.0" *If this number is higher than the version number known by the READER then the reader should not accept to read on. This version number is the version number of ODEON when the format was last revised. That is to say, if the READER is ODEON 10.0 (or another program aware of* ODEONArrayVersion="10.0"*) then it should not accept data written in* ODEONArrayVersion="10.2". *This on the other hand implies that if your WRITER does not use any specifications added in a later* ODEONArrayVersion *then you might consider using the lowest version number possible, to make it compatible with READERS not knowing of the higher version. READER should assume no more than 4 decimals in the version number.*

Gain="8" *overall in dB per octave band – defaults to 0.*

Delay="0.007" *Delay in seconds of the entire array.*
ArrayCoordSys="Absolute" *Can be "*Rel. hanging*", "*Rel. standing*" or "*Absolute*". Most programs will probably export as "*Absolute*". ODEON has the two other options in order to allow automatic aligning*

and sorting of transducers relative to the upper (rel. hanging) or lower (rel. standing) transducer. The orign of the transducers can be offset using the node CoordSysOffSet *node.*

FarFieldDistance="-1" *In metres, -1 indicates that ODEON should make its own estimate of the far field distance. For distances greater than* FarFieldDistance *ODEON will use a pre-calculated balloon (calculated for that distance). This far field balloon is calculated and handled entirely by ODEON.*

FarFieldResolution="2" *Far field balloon resolution in degrees: 1, 2, 3, 5 and 10 degrees allowed.*

NumberOfSubBands="6" *Frequency resolution per octave band applied for phase summation in the calculations. Can be 3,6,9… A resolution of 6 is suggested as a good compromise between calculation time and quality of results.*

Nodes to ArraySource
Position
Orientation
CoordSysOffset
EQ
Transducer (there can be multiple)

Position Node
Attributes to Position
X="**1**"
Y="**1**"
Z="**1**"
Uses the same coordinate system as in ODEON and as in the room to be imported into. Defaults to (1,1,1) and can easily be changed from within ODEON.

Orientation node
Attributes to Orientation
Azimuth - +/- 180°, around vertical axis, counter-clockwise is positive.
Elevation – +/-90°, up is positive and down is negative.
Rotation"-10" – +/-180°, counter-clockwise rotation around loudspeaker axis is positive.

Nodes to Orientation
Vector

Vector node
Attributes to Vector
X="**1**"
Y="**0**"
Z="**0**"
Is used for defining orientation, need not be a unit vector. Above is the default orientation of an array or a loudspeaker – right turned coordinate system assumed. Vector is just another way to specify Azimuth and Elevation - not needed if Azimuth and Elevation have been specified – defaults to (1,0,0). READER should allow both, WRITER should normally just use the most comfortable one.

CoordSysOffSet node
Offset of array coordinate system, see ArrayCoordSys.
Attributes to CoordSysOffSet
X="**1**"
Y="**0**"
Z="**0**"

EQ node
Overall equalization in dB of the array speaker, one value for each octave band.

Attributes to EQ

Octave_31="**0**"
Octave_63="**0**"
Octave_125="**0**"
Octave_250="**0**"
Octave_500="**0**"
Octave_1000="**0**"
Octave_2000="**0**"
Octave_4000="**0**"
Octave_8000="**0**"
Octave_16000="**0**"

ODEON will only make use of 63 to 8000 Hz octaves; other bands are ignored by ODEON. Any omitted band defaults to 0 dB.

Transducer node *(there should be at least one transducer in an array, typically there will be more)*

Transducer (all nodes below included)

Attributes

Description="A descriptive text"
Gain="5"
Overall in dB per octave band – defaults to 0
Balloon="Omni.So8"

*Balloon data are stored in a directory known to the reader e.g. "*C:\ODEON9Combined\DirFiles*". The balloon name may include a sub directory name (it probably should), e.g.* Balloon="LspManufacturerName\SpeakerModel23.CF2"*. Balloons can be in* .CF1, .CF2 *and* .So8 *formats.*

Delay="0.012" - *Delay of that transducer in seconds.*

InvertPhase="false" *Whether phase is inverted 180° - defaults to FALSE*

SampleRate *e.g.* 44100 Hz *or* 48000 Hz. *Not in use yet. Specifies the sample rate if the filter for a transducer is an FIR filter.*

PhaseCF2="false" *True if directivity balloon containing phase angles should be used for the transducer. See section on "phase balloons" at the end of this appendix.*

For transducers which have been assigned a directivity pattern in the Common Loudspeaker Format CF2 version 2, the transducer may belong to a multi part speaker, e.g. having separate balloons for the low frequency unit and the high frequency unit in a loudspeaker. In that case, a filter (e.g. low pass and high pass), may also be assigned to each transducer. This is what CLFPartNo, CLFPartMax and CLFFilter is for.

CLFPartMax="2"
How many transducers with CLF2v2 balloons belongs to this speaker (array)
CLFPartNo="1"
Which part of a multi part CLF is this transducer (e.g. part 1 or 2 of a two-way speaker)
CLFFilter="true"
Whether a filter assigned to the transducer in the CLF2v2 file (e.g. a low pass or a high pass filter)

Domain="**Frequency**"

*So far options are "*Frequency*" for beam-steered, otherwise "*Octave*" (future should include "Time" in which case an attribute,* SampleRate, *will be needed e.g.* 44100 Hz *or* 48000 Hz*)*

Nodes

Position
Orientation
DomainData

DomainData node

There are two kinds of domain data, so far also described in figure E2. If Domain= "Octave", simple octave band equalization is applied to each transducer. This can be used for exporting and

importing simple array types as they are defined inside ODEON. The format is convenient since it is compact, and in some cases it may even be used for typing data manually into a text file.
If Domain="Frequency", then beaming-filters are entered as an amount of Complex numbers per octave band. We suggest that NumberOfSubBands, an attribute of the ArraySource, is set to 6.
Attributes
DomainData has no attributes

Nodes to DomainData
EQ
or
Octave_31, Octave_63, Octave_125, Octave_250, Octave_500, Octave_1000, Octave_2000, Octave_4000, Octave_8000, Octave_16000

EQ node
EQ node is only present if Domain="FullOctave" (Attribute of Transducer)

Attributes to EQ
Octave_31="**0**"
Octave_63="**0**"
Octave_125="**0**"
Octave_250="**0**"
Octave_500="**0**"
Octave_1000="**0**"
Octave_2000="**0**"
Octave_4000="**0**"
Octave_8000="**0**"
Octave_16000="**0**"

ODEON will only make use of 63 to 8000 Hz octaves; other bands are ignored by ODEON. Any omitted band defaults to 0 dB.

Octave_31, Octave_63, Octave_125, Octave_250…. nodes
These nodes are only present if Domain = "Frequency", then a number of Octave nodes are defined – each of these Octave nodes have Sub nodes.
Nodes
Each Octave band has the centre frequency f_c, defined according to ISO (31.5, 63, 125, 250, 500, 1000, 4000, 8000 and 16000 Hz). For each of the octaves there are N_s (number of Sub-bands) nodes of the Sub type, and the center frequency of the sub bands are defined from the following algorithms:

The frequency f_1 of the lowest sub-band in an octave is defined as follows:

$$f_1 = \frac{f_c}{\sqrt{2}} \times 2^{\frac{1}{2 \times N_s}}$$

And the following frequencies f_n sub-bands are defined as:

$$f_n = f_{n-1} 2^{\frac{1}{N_s}}$$

Where n=2 to n

The 6 sub bands (Ns=6) centered around 1000 Hz have the following centre frequencies:

Sub band number – n	Frequency (Hertz)
1	749.153538438340749
2	840.896415253714543
3	943.874312681693497
4	1059.46309435929526

5	1189.20711500272106
6	1334.83985417003436

Frequency of n^{th} sub band in 1000 Hz octave for $N_s = 6$

Results of calculations should be for full octave bands for the octave bands 63, 125, …8000 Hz
ISO suggests that center sub octave frequencies should be derived from 1000 Hz. For an uneven number of bands e.g. 1/3rd octave bands this gives us one band below, one band at, and one band above the center frequency of the Octave center frequency – so the 3 sub-octaves are in balance relative to the octave band – however for an even number of sub-band frequencies thing becomes unbalanced if using ISO frequencies; there will be 2 sub-bands below and 3 sub-bands above the full octave band centre frequency (or opposite 3 below, 2 above)

Attributes
Re
Img
The energy of the transducer is emitted in N_s Sub nodes. The center frequencies of the Sub bands are centered around the full octave band centre frequency, in order best to simulate the energy in each octave band. If N_s is odd, e.g. 5 then these frequencies will coincide with ISO centre frequencies. Be aware though that the centre frequencies used will differ if an even number (e.g. 6) is used.

Getting the voltage and energy right
Values are in tension [V]. The values should be reduced by a factor which compensates for the NumberOfSubBands. N_s used if N_s sub-bands are used, then the Re and Img attributes of each node should be multiplied by a factor $\frac{1}{\sqrt{N_s}}$.
If there were 6 sub-nodes in each band, and Re= "1.15534266201273234" and Img= "0.0" for each of them, then the equivalent voltage for one sub-band representing the total power in that band would be 1.15534266201273234xSqrt(6)=2.83 V. 2.83 V is the standard voltage for which sensitivity at 1 metre is given for loudspeakers, so with this setting it will reproduce the sensitivity values at a distance of 1 metre, see the Dipol_Domain_Frequency.xml sample. 2.83 V may seem like an arbitrary value, but it is generally agreed upon as 'standard voltage'– this is the voltage at which an 8Ω speaker deliver 1W. The reason why the industry has moved from 1W to 2.83V? Loudspeakers rarely have a frequency-linear impedance (of 8Ω), whereas an amplifier is actually fairly capable of supplying constant voltage.

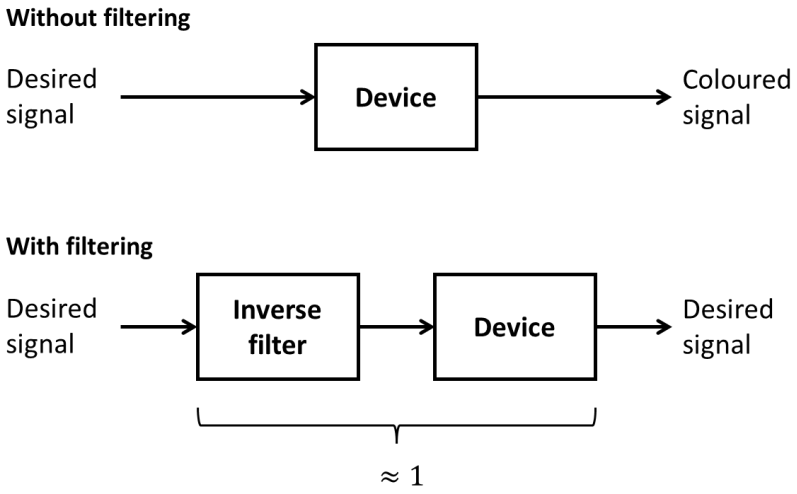
Position node
Attributes
X="**1**"
Y="**2**"
Z="-0,324"
Position of Source of transducer origin given in metres. Position defaults to (1,1,1)

Orientation node
Attributes
Azimuth="27" - +/- 180°, around vertical axis, counter-clockwise is positive
Elevation="-10" – +/-90°, up is positive and down is negative
Rotation"-10" – +/-180°, counter-clockwise rotation around loudspeaker axis is positive
Nodes
Vector

Vector node
Attributes
X="0,993768018134063"
Y="0,0694910287794796"
Z="0,0871557402186753"

Appendix D: Inverse filter design

The inverse filter tool makes it possible to create a regularised inverse filter for a given device's impulse response.



Principle of inverse filtering. Without filtering, the signal can be coloured when passing through a device (e.g., headphones, a microphone or a loudspeaker). The role of the inverse filter is to compensate for the device so that it becomes "transparent" in the chain.

The tool is used for two different applications in ODEON:

- **Auralisation:** the inverse filter compensates for the headphones' response, so that auralisations sound as without headphones. The tool is accessed from the Auralisation setup and requires a measured impulse response for a selected pair of headphones (1 or 2 channels).
- **Measurements:** the inverse filter compensates for the source (loudspeaker) or the receiver (microphone) during a room impulse response measurement. For that purpose, go to Tools > Create Inverse filter (.wav).

The inverse filter can be created for one or two channels. The menu enables you to visualise, control and modify the inverse filter, both in the time and the frequency domain. Nevertheless, the process is kept as automatic as possible.

Calculation principles

For the inverse filter to be effective, the convolution between the headphone impulse response and the inverse filter should be close to a Dirac function. In the frequency domain, this is equivalent to the product of the two transfer functions being equal to 1.

The inverse filter is calculated in the **frequency domain**, which is obtained by applying a Fast Fourier Transform (FFT) to the device's measured impulse response. The idea is then to invert the device's transfer function in the frequency domain. However, a simple inversion is not recommended because it may be erroneous in frequency regions where the response level is low, as it may be contaminated by background noise. In particular, if the frequency response has clear notches, the inverse filter might contain peaks that will translate into ringing artefacts.

A way of circumventing that issue is to make use of *regularisation*. We follow a methodology from (Gomez-Bolaños, et al., 2016), which proposes an automatic regularisation, both on notches and on level:

- Notches are identified by comparing the device's frequency response to a smoothed version of it.
- In terms of level, we regularise the response when its level is below its maximum amplitude minus 20 dB.

The equation for the inverse filter $G(\omega)$ is

$$G(\omega) = \frac{H^*(\omega)}{|H(\omega)|^2 + \alpha^2(\omega) + \sigma^2(\omega)}.$$

- $H(\omega)$ is the device's frequency response. $H^*(\omega)$ is its complex conjugate.
- $\alpha(\omega)$ is a regularisation term related to the level of $H(\omega)$.
- $\sigma(\omega)$ is a regularisation term related to the notches of $H(\omega)$.

In regions where $|H(\omega)|$ is small, α and/or σ dominate the denominator and prevent G from reaching too high values. Both α and σ make use of a smoothed frequency response $\widetilde{H}$ over half octaves, which basically represents $|H|$ without notches.

The resulting multiplication between the device's frequency response and the inverse filter's is almost flat, except notches, which are not perceived by the human ear if they are narrow enough.

This is an automatic process, so you don't need to specify any regularisation parameters.

Notch regularisation: calculation of $\sigma(\omega)$

The term $\sigma(\omega)$ compares the device's frequency response $H(\omega)$ with its smoothed magnitude $\widetilde{H}(\omega)$. It is calculated as follows:

$$\sigma(\omega) = \begin{cases} \widetilde{H}(\omega) - |H(\omega)| \; if \; \widetilde{H}(\omega) \geq |H(\omega)| \\ 0 \; else. \end{cases}$$

When the smoothed response is larger than the original response (indicative of a notch), we use the difference between the two responses as a value of $\sigma(\omega)$. The larger the notch, the larger the value. In other cases, σ is set to 0 (i.e., no regularisation).

Level regularisation: calculation of $\alpha(\omega)$

A threshold is defined corresponding to the maximum of the frequency response magnitude minus 20 dB,

$$\epsilon = \frac{\max(\widetilde{H})}{10}.$$
$$\alpha(\omega) = \max\left(\frac{\epsilon}{\widetilde{H}(\omega)} - 1{,}0\right)\widetilde{H}(\omega).$$

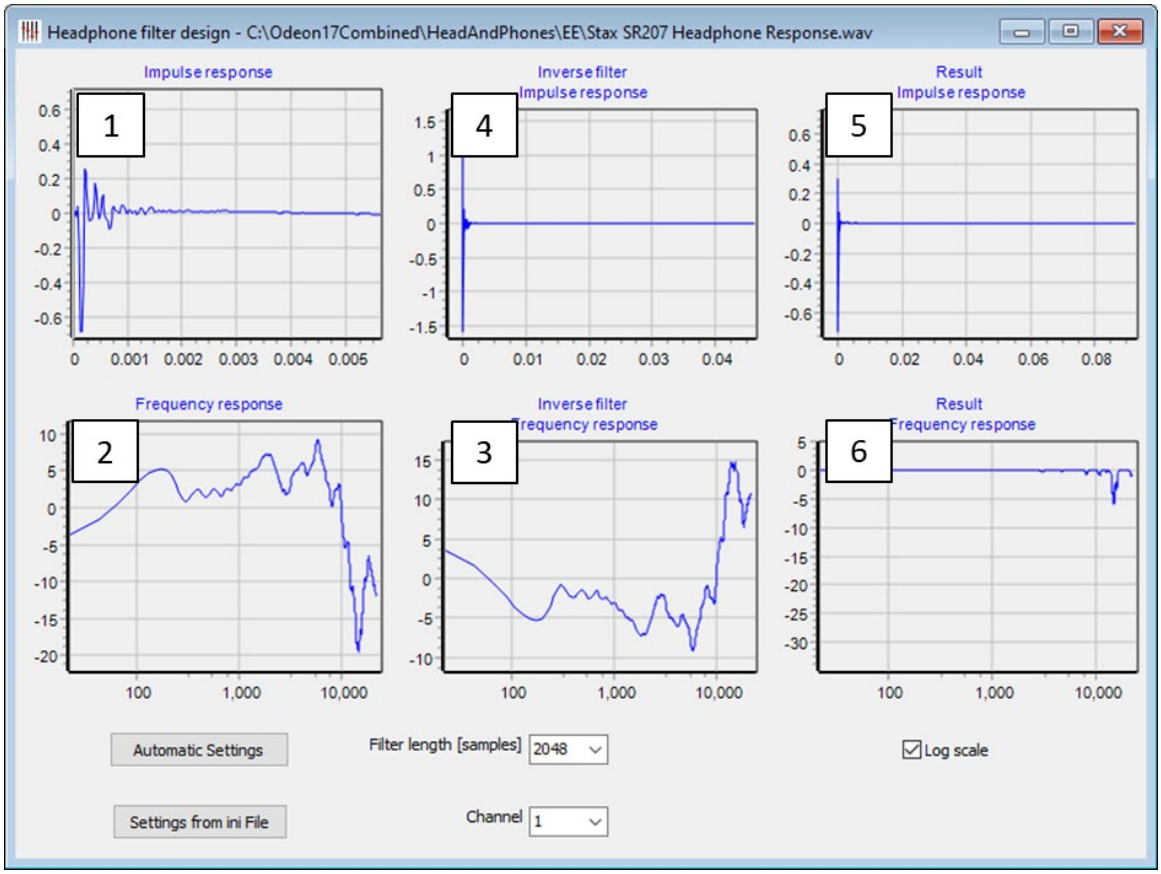
When $\widetilde{H}(\omega)$ is larger than the threshold, then $\alpha(\omega) = 0$ (no regularisation). Conversely, when $\widetilde{H}(\omega) < \epsilon$, then $\alpha(\omega)$ has a strictly positive value, which prevents the denominator to be too close to 0.

Calculation of the inverse filter in the time domain

So far, the inversion has been carried out in the frequency domain, so an inverse Fourier transform (IFFT) must be performed to obtain the inverse filter in the time domain. A typical characteristic of the inverse filter calculated with regularisation is that it is *non-causal*, i.e., the filter starts responding at negative times. This behaviour is managed by using a *minimum-phase filter* that has the same

magnitude response as the inverse filter, but which does not aim at correcting the phase response of the device (Norcross, et al., 2004).

Interface of the inverse filter tool



The interface contains 6 different graphs (presented in chronological order):

7. **The device's impulse response in time domain**, as measured and stored in a wave file. Note that for headphones, these impulse responses should be relatively short.
8. **The device's frequency response in frequency domain**, obtained from Graph 1 by FFT.
9. **The calculated inverse filter frequency response**, obtained by regularised inversion of Graph 2.
10. **The inverse filter's impulse response in the time domain**, as it will be saved as a wave file. It is obtained using the minimum phase filter algorithm on Graph 3.
11. **Result impulse response** shows the convolution between Graph 1 and Graph 4, for verification. Ideally, this graph should be as close as possible to a Dirac function.
12. **Result frequency response** shows the product between Graph 2 and Graph 3, for verification. Ideally, it should be a flat line equal to 0 dB. Narrow notches are acceptable for auralisation purposes.

Overall, the process is fully automatic, but it can still be adjusted via two parameters, namely the *onset time* and the *filter length*. Their values are suggested automatically (either if you open the device's impulse response for the first time, or if you click on the Automatic settings button).

The **onset time** indicates the start of the impulse response. In the inverse filter calculation, we discard the signal before the onset time. The onset time is displayed on the impulse response graph (Graph 1) as a black vertical line. It is automatically detected at the point where the amplitude is

40 dB lower than the peak. The user can modify the onset time by clicking and dragging the black line. Note that it is not possible to place it after the impulse response peak.

The **filter length** is the length of the inverse filter. The device's impulse response is truncated to this parameter before applying the FFT and calculating the inverse filter. It is a power of 2 for an optimal use of the FFT algorithm. The parameter is chosen in the corresponding drop-down list at the bottom of the window (possible filter length values between 1024 and 32768). The filter should be applicable to frequencies down to 20 Hz, which means it should be at least 1/(2*20 Hz)=1/40 Hz, i.e. 25 ms long. Depending on the sampling rate, the proposed filter length is the next power of 2 in number of samples that corresponds to this duration. A longer filter is more accurate, but it is also slower.

Note: for typical sampling frequencies of 44.1 kHz and 48 kHz, the automatic filter length is 2048 samples.

When closing the window, these two parameters are saved in a *.ini file. The next time the tool is opened for that particular device impulse response, the onset time and the filter length are taken from the *.ini file instead of being calculated automatically. If the ini file exists, it is always possible to reload it with the appropriate button at the bottom of the window.

Note: this ini file is not compatible with versions earlier than ODEON 16.

Remarks on multichannel files

The tool can be used for a two-channel impulse response (e.g., the two channels of a pair of headphones). In that case, the same parameters (onset time, filter length) are applied to both channels.

During the automatic detection process, the earliest onset is chosen as the onset time for both channel

For a multichannel impulse response, you can select which channel is displayed in the dropdown list at the bottom of the window.

Appendix E: Head Related Transfer Functions (HRTFs) and digital filtering

To create binaural simulations, a set of HRTFs is needed. The HRTFs are different from subject to subject. In principle, and for best accuracy, you can measure your own and import them into ODEON using the Tools>Create filtered HRTF menu entry in the ODEON program. Measuring HRTFs are, however a complicated and costly task, so using the supplied ones is the simplest option.

If you should be interested in creating your own sets of HRTFs for ODEON, additional information can be found when clicking F1 when inside the ODEON program. Here search for HRTF.

The imported HRTFs to use for auralisation are pre-filtered into octave bands in order to reduce calculation time. The octave band filter parameters for the selected filter bank can be seen on the filter bank name at the Auralisation Setup menu. The filter parameters are:

M

The M value is taken into account if the "Apply enhancement" option is checked. If the file name contains the 'word' *Mddd* where *ddd* is a floating-point number, then localization enhancement was applied to the HRTF's (Zang, et al., 1998). This means that frequency dips and notches in the individual HRTF's have been exaggerated in order to improve the directional cues in the HRTFs. The M-factor determines how much the dips and notches have been exaggerated; If M is 0 then the effect is neutral, a value of 3.0 improves localization without too much undesired colouration. An M value greater than 3.0 does not seem to give any noticeable advantages whereas a value less than 3.0 gives less colouration. The enhancement algorithms are further developments of those used in earlier versions of ODEON, as a result the *M* factor can be set as high as 3.0, allowing a significant improvement of the 3D experience through headphones without noticeable drawbacks.

A

When an *A* is appended after the *M*-factor, this tells that Minimize colouration effects (diffuse field approach) was not enabled so the HRTFs were optimized for Anechoic conditions (no reflections present). If no A is found in this place in the name then ODEON has attempted to minimize colouration effects; the enhancements applied may give some colouration effects because some frequencies are amplified for individual directions. When this option is checked, ODEON will try to accomplish that colouration is kept at a minimum in a multi-reflection environment, that is if the average frequency response for all directions in the set of HRTFs is kept neutral.

Sample rate

The sample rate of the HRTF. This sample rate should be the same as the sample rate of the signal files (anechoic recordings) to be used. The supplied HRTFs are sampled at 44100 Hz.

A_{pass}

Ripple of octave band filters in dB. Smaller is better, 0.5 dB is sufficient.

A_{stop}

Maximum possible attenuation of octave bands. To allow complete attenuation of all reflections of a 16 bit signal (96 dB dynamic range), A_{stop} should be 96 dB, however due to auditory masking we

are not able to hear such differences so 40 dB is probably sufficient. Smaller A_{stop} leads to shorter calculation time (of the BRIRs).

Band overlap in percent

Octave bands implemented using FIR filters are not completely rectangular, it takes some frequency span before they attenuate completely. An overlap between the filters of 100 percent gives a smooth transition between the filters, which is probably a more realistic representation of real-world reflections than with shorter overlaps. At the same time, long overlap gives shorter calculation time (of the BRIRs).

If you should need to use filters with other filter parameters e.g. A_{stop} being 96 dB you should create a filtered set of HRTF's with these parameters, use the File|Create filtered HRTF's option. Then from within your room, select the new filter bank from the Auralisation Setup.

The ODEON installation includes some HRTFs: the Kemar (Gardner, et al., 1994), which has to be manually imported from the ODEON folder, and Subject_021Res10deg (Algazi, 2001) which is already imported. If you need HRTFs other than these ones, you should create a text file following the same format as used in the files Unity.ascii_hrtf, Kemar.ascii_hrtf and Subject_021Res10deg.ascii_hrtf. These files can be found in the \HeadAndPhone\EE\ and \HeadAndPhone\EC\ directories. To import a set of HRTFs, select the Tools|Create filtered HRTF's option, then select the specific HRTF ASCII file e.g. C:\ODEON...\HeadAndPhones\EE\Kemar.ascii_hrtf, finally specify miscellaneous parameters when the import dialog appears – for help on these parameters please press F1 from within the dialog. You may also desire to import a set of HRTFs which has already been imported in order to specify an alternative filtering approach e.g. to enhance the HRTFs in different ways.

Headphone filters and HRTF pairing

It is possible to compensate for non-linear frequency response of headphones. When a headphone is selected, ODEON will filter the audio output with a minimum phase filter, which has a frequency response inverse to that of the headphones.

A number of headphone filters are supplied in ODEON's .hph format. Filters ending on .ee.hph are measured on a dummy head at the entrance of a blocked ear canal whereas filters ending on .ec.hph are measured at the end of the ear canal (at the ear drum, so to speak). The selected headphone filter should match the HRTFs used; for example, the Subject_021Res10deg.hrtf doesn't have an ear canal, therefore an .ee filter should be used, whereas the Kemar.hrtf does have an ear canal, so the .ec filters should be used. If the corresponding filter for the headphone used is not available then a generic filter matching the set of HRTFs may be used, e.g. Subject_021Res10deg_diffuse.hph. If a diffuse field filter (equalization) is selected, the results are filtered in order to obtain an overall flat frequency response of the HRTFs; that is, the average frequency response of all the HRTF filters are calculated and the auralisation results are filtered with the inverse of that. If using headphones which are diffuse field equalized (most headphones attempt to be) and a matching headphone filter is not available, then the matching diffuse filter headphone filter can be used.

For your convenience, two directories with matching HRTFs and headphone filters are installed with ODEON - the \HeadsAndPhones\EE\ and \HeadsAndPhones\EC\ directories. The first directory contains a set of HRTFs which were measured on a live subject with blocked ear-canal by the CIPIC Interface Laboratory (Algazi, 2001) along with our matching .ee.hph headphone filters. The next ones contains the well-known Kemar HRTFs, which includes ear-canals along with our matching .ec.hph filters. One of the directories can be selected in the Options>Program setup>Auralisation setup dialog – once done

- matching the HRTFs and headphone filters can be selected in the same dialog, as well as in the Auralisation setup in the individual room.

If installing new HRTFs, headphone filters are acceptable in the .wav format. In that case the filters should contain the impulse response(s) of the headphone as measured on a dummy head of the same type as the one selected in the HRTF drop down menu (i.e. with or without ear canal or a corresponding ear coupler). The filter may be one or two channels; two channels are desirable if compensating a specific headphone, which is preferable than compensating for the model (the actual headphone may deviate slightly from the model specifications). The measurement of the impulse response of headphones can be done using ODEON's Measurement System (see Chapter 12), and creating the inverse filter to be used will be taken care of by ODEON.

Appendix F: Sound Pressure Levels for Binaural Auralisations

Binaural auralisation results must be presented over headphones. Ideally, the sound pressure level at the ear canals produced by the headphones should be the same as is obtained in the real room (if the room exists). However, this is challenging, as the playback level depends on many different parameters. This appendix presents guidelines on how to adjust the levels of your auralisations, either on a relative scale or an absolute one.

Adjusting levels

It is important to play auralisation files at the right sound level for them to sound realistic. If playing a simulation of a voice at an unrealistically high level, the speech intelligibility may be overrated. If playback levels are too high, echo problems may be exaggerated, because echoes that would be below the audible threshold may be perceived. Another very common effect of presenting auralisations at too high levels is that the room sounds too reverberant. This is because the full decay may be audible, whereas in reality we would typically hear about 60 dB of decay only.

The levels presented in auralisation samples created by ODEON are influenced by:

- The HRTFs.
- The level in the input signal file, e.g., the RMS value or Leq_A.
- The calculated Sound Pressure Level, which is based on geometry, sources, receiver positions, materials, etc.
- The overall recording level in the Auralisation setup.
- The Recording Level (Rcd. lev) in the Auralisations display of the JobList - if offline convolution is used.
- The mixer levels (Mix. Lev. in the JobList) if offline convolution is used.
- The gain in the Streaming convolution dialog if the real-time convolution option is used.
- The output gain of the sound card.
- The computer's volume settings.
- The sensitivity of the headphones.
- The coupling between the headphones and the subject's ears.

All these factors in combination make it very difficult to predict the exact output level of the auralisation.

Maximised playback levels for maximum dynamic range

If you are only interested in the sound quality in your auralisation files, you may focus on maximising the Output Level (Max. Out level in the auralisation display within the Job list, for single auralisations in the convolver or for mixes in the mixer), while maintaining it below 0 dB.

If using the Streaming convolution option, ODEON will maximize the auralisation output level. When changing the input signal or BRIR from within this display, you should click the Maximize Gain button to maximize the gain for the new setup.

Relative playback levels

In some cases, you may be interested in obtaining correct relative levels (e.g., for comparisons between different seats in a concert hall). In the case of offline convolutions, you should remember to use the same levels (recording levels and mixer levels in the convolver and mixer tables of the

Auralisations window) for the samples to be comparable; it is a good idea to use the same input signal file to make sure that levels are the same at this point. If you wish to compare across different rooms, you should also be aware of the source gain you are using in each room.

If using the Streaming convolution, ODEON will maximize the auralisation output level automatically. Therefore, if you wish to compare different rooms, you should make sure to use the same Gain in the Streaming convolution window in every room.

Absolute playback levels for headphone auralisation

Setting the level to an absolute level - so the subject presented to the auralisation sample experiences the same level as would have been the case in the real room - is tricky as it involves every part in the signal chain.

To obtain a reasonable correct level, a first approach is to adjust the auralisation output against levels in the room in which you actually are. If you are simulating a voice, try to compare the level of the playback with the level of somebody speaking in your room. This method should make it possible to make a rough adjustment, and it is certainly better than none.

A more precise method is to use the calculated SPL_A as a reference (if it is calculated at an absolute level):

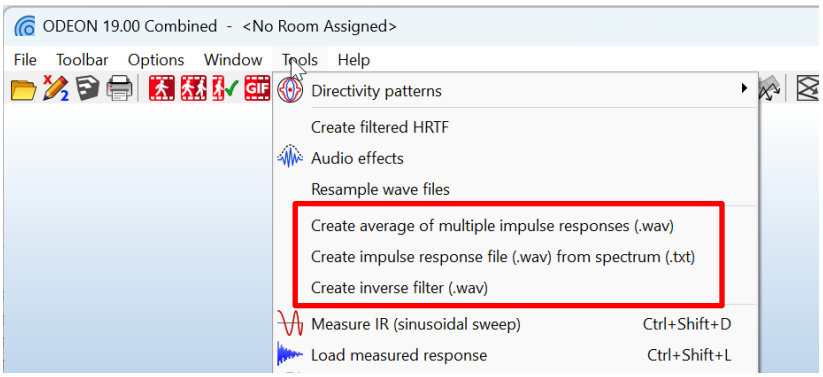
- Present the auralisation signal over a loudspeaker in the room in which you are sitting.
- Measure the sound pressure level in the room at the position where you will be listening, and adjust the output level of the loudspeaker-amplifier until the measured Leq_A corresponds to the calculated level. At this point you have a physical reference level, which can be used for calibration of your auralisation playback level.
- Switch between playing your auralisation sample over headphones, and over the loudspeaker, while adjusting the level of the auralisation playback until the levels are the same.

This method is somewhat inspired by the old Barkhausen method for measuring loudness level in Phon, and should at least in principle allow perfect calibration of the level (the resulting level being within one subjective limen).

Appendix G: Impulse Response processing tools

(Auditorium and Combined editions only)

A group of tools makes it possible to perform a number of advanced operations on impulse responses to enhance measurements and auralisations. Currently, three tools are available at the Tools menu in the main ODEON bar.



Create average of multiple impulse responses (.wav)

You can load as many impulse responses as you want at once (use SHIFT/CTRL+select in the open dialog) and create an average Impulse response out of them. The tool is particularly useful when you want to measure the response of headphones (using an artificial ear or a dummy head) or the response of a speaker at the same position. Since every time you measure there might be slight differences in the response, it is recommended to take more than one measurement, to minimize variations. Use settings described below.

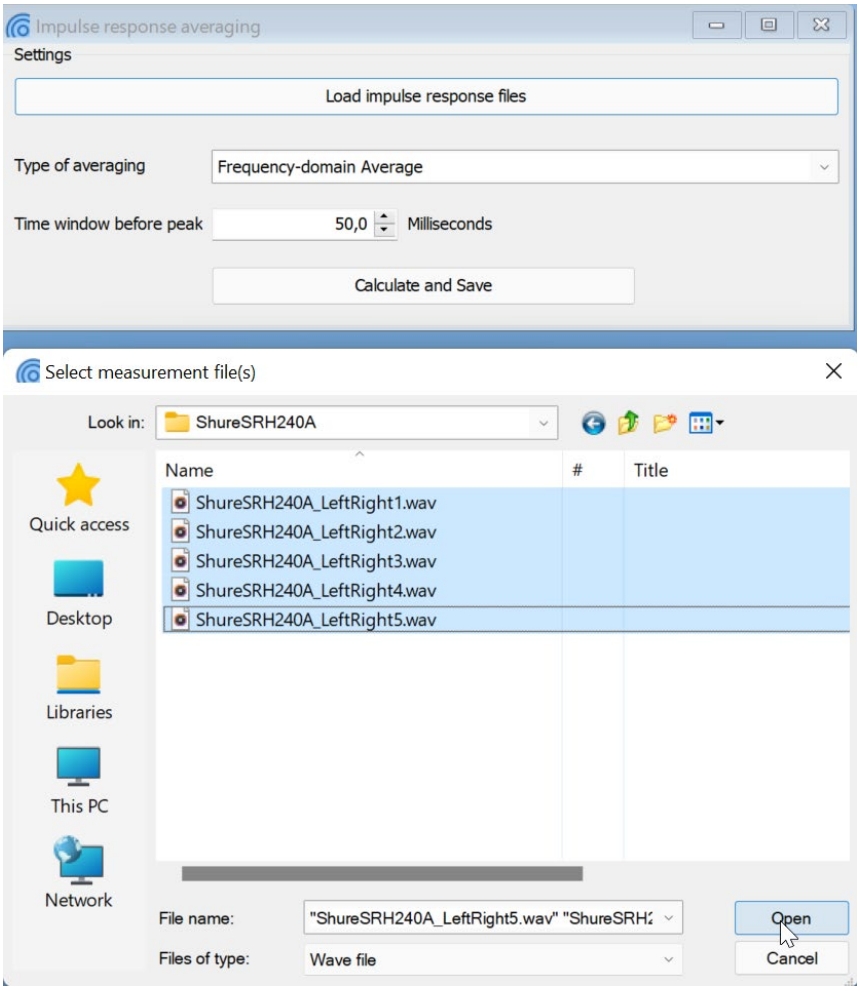
Type of averaging

There are two ways to create the average:

- In Frequency-domain Average, where the Impulse responses are first converted to Frequency responses using FFT, averaged and then converted back to an Impulse response (time domain) with zero imaginary part and minimum phase. This is the default setting yielding the most stable results, when there are many 'outliers' in the selected group of responses. This average is preferred for *headphone measurements*.
- In Time-domain Average (also called ensemble average), where the Impulse responses are averaged directly in the time-domain sample by sample. In most of the cases, both time-domain and frequency-domain averaging yields the same result. This average is particularly *useful for suppressing noise*.

Time window before peak

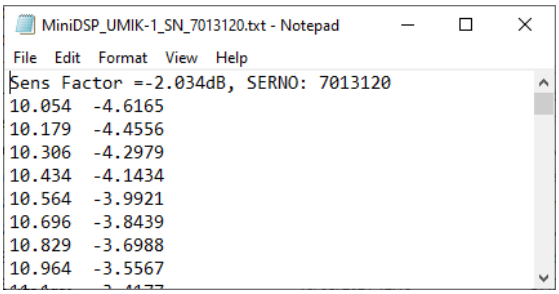
This setting helps detecting the peak of impulse each response successfully, so that they are perfectly aligned during averaging. The length of the window gives enough length to include any gradual build-up of the energy at the onset (just before the peak).



Calculate and save

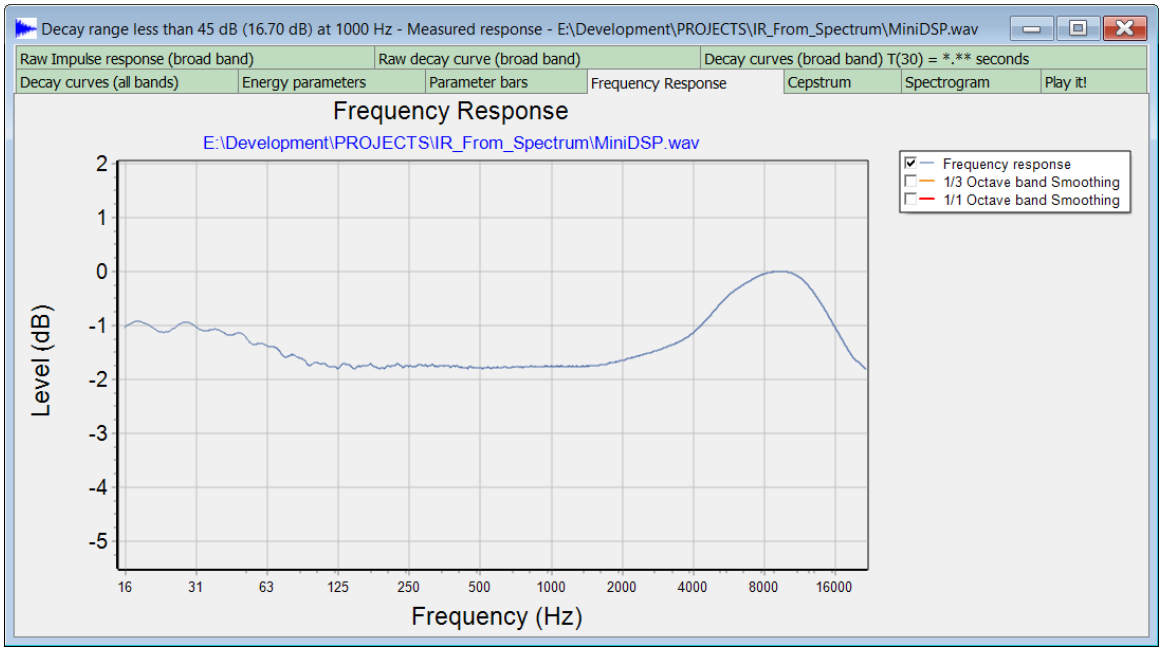
When all files are selected and loaded, press *Calculate and Save* to create the average impulse response.

Create impulse response file (.wav) from spectrum (.txt)



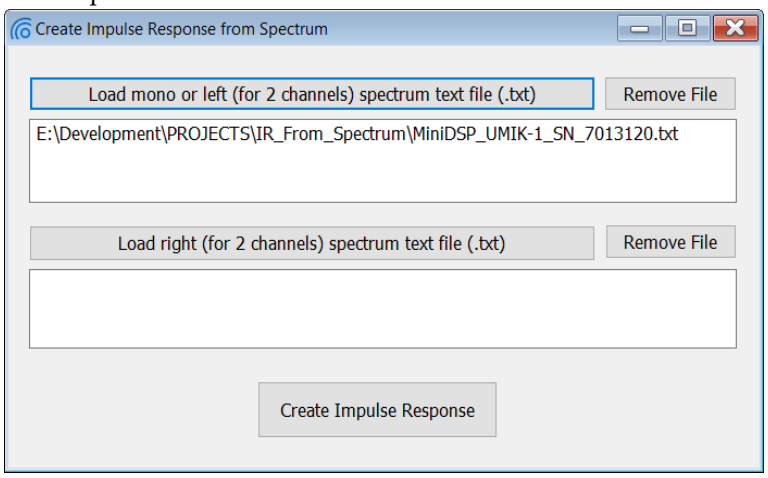
The tool uses up to two .txt files that contain the spectrum of a device (microphone, loudspeaker, headphone) and creates a 1-channel or 2-channel impulse response file from it. The .txt file is typically obtained from the manufacturer of the device and should contain one column for the *frequency* and one column from the *dB level*.

Such a .txt file is displayed on the right figure. This particular file accompanies the USB microphone UMIK, by MiniDSP, and corre-sponds to the particular serial number of our device. Therefore, it is fully representative of the frequency response of the item. The file has a total of 616 lines with frequencies from 10.054 to 20016.816 Hz. You don't have to delete the first information line, as ODEON will automatically identify where the actual data begin. The tool starts the process, by interpolating a high-resolution spectrum (frequency response) from the data given in the .txt file. The interpolated spectrum for the .txt file shown above is illustrated in the following figure.



The high-resolution spectrum is the then converted to time-domain using Inverse FFT and assuming zero imaginary part and zero phase.

Press 'Create Impulse Response' as in the screenshot on the right. The tool will create an impulse response which would give the same spectrum as the original one. This impulse response can be loaded in the next tool to obtain an inverse filter that can be used during measurements or auralisation, in order to neutralize the frequency response of the device.

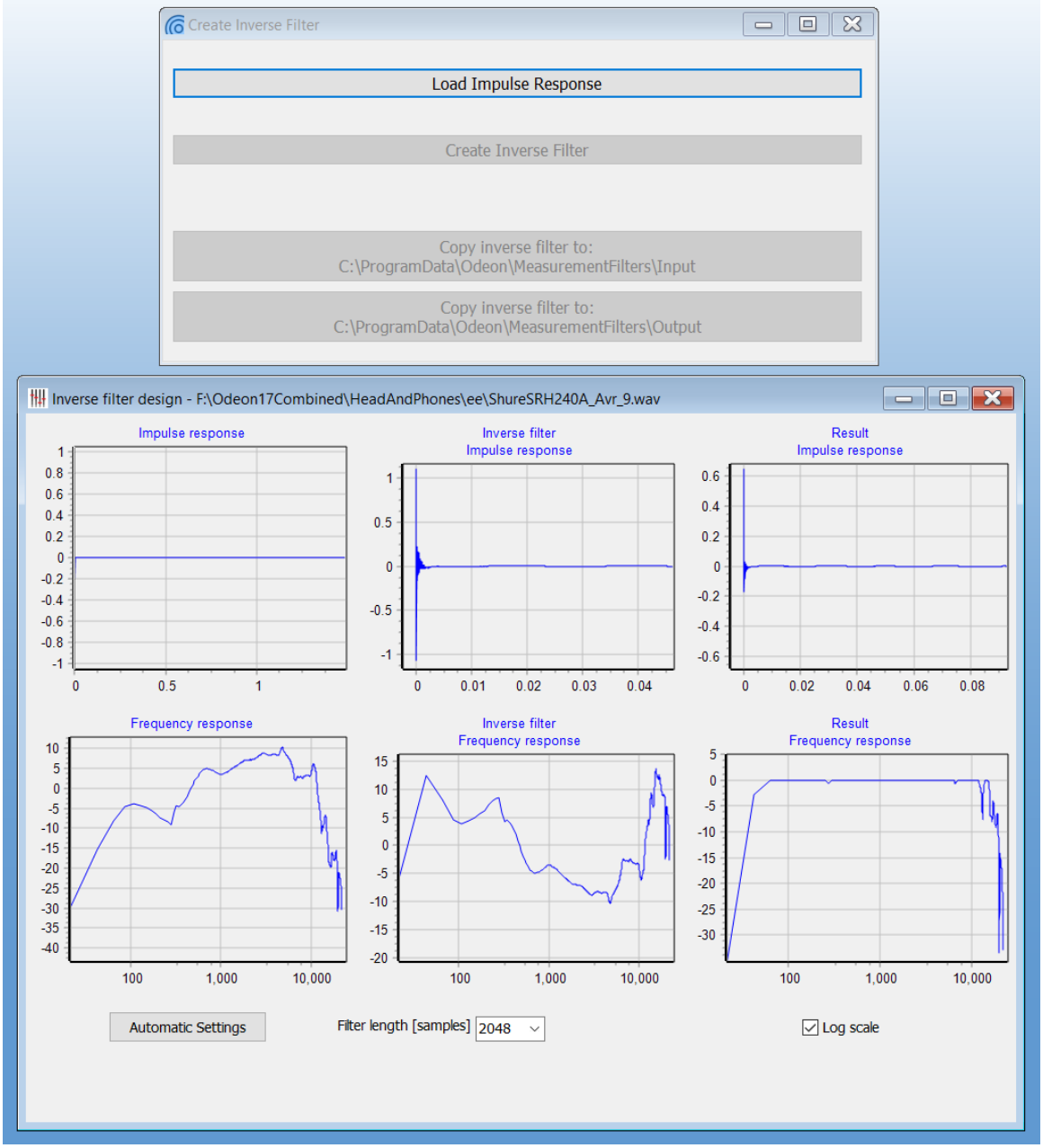


Create inverse filter (.wav)

The tool loads an impulse response, calculates its FFT frequency response and then the inverse spectrum. This inverse spectrum is finally converted back to a time-domain impulse response, which can be used either in measurements or auralisations to remove any frequency colouration from the device in use (see below in typical cases). The tool uses the calculation engine described in Appendix D. The following steps should be followed for using the tool:

- Load an impulse response using the Load Impulse Response button.
- Press the Create Inverse Filter button to calculate the inverse filter out of the impulse response.
- ODEON will now open another window, showing the calculated inverse filter and the corresponding impulse response.
- Close the window. You will be prompted to save the file.

The tool can process up to 2-channel files.



Typical use cases

Although the tools can be used alone, they will be mostly useful when used in combination for the following cases:

Headphone measurements for auralisations

Before making any auralisation, it is advisable to compensate for the frequency response of the actual used Headphone in the Auralisation setup. This is because the headphone has to remain as neutral as possible in the playback chain and do not colourize the sound file with each own frequency response.

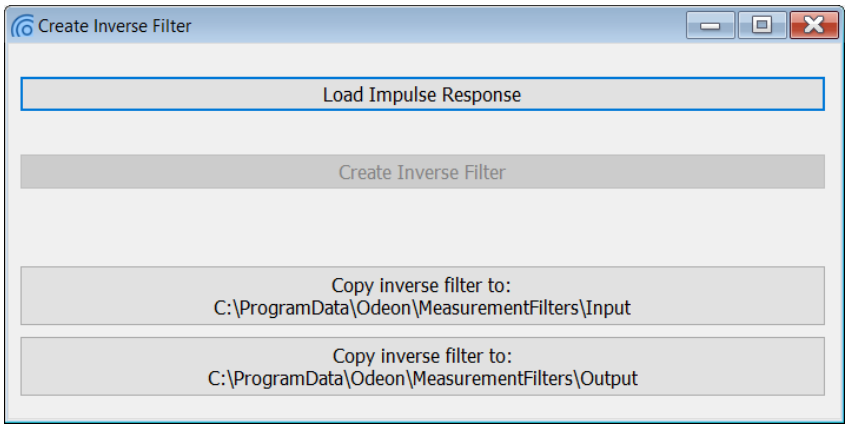
ODEON comes with some default headphone filters that can be used directly in the Auralisation setup. However, if a particular model is not in the list, you can make measurements yourself, using an artificial ear or a dummy head with microphones on its ears, together with ODEON's Sweep Measurement Facilities.

- You should first obtain 3 to 5 impulse responses, by removing and repositioning the headphone each time on the artifial ear or dummy head. This will ensure that you will measure a variety of slightly different positions on the ear, as it happens in real-life.
- Use the Create average of multiple impulse responses (.wav) tool to obtain an average Impulse Response from the previous measurements.
- Use the Create Inverse filter (.wav) tool to make an inverse filter for auralisations
- Alternatively, simply copy the averaged Impulse Response (.wav) file in ODEON'S HeadAndPhones\ee folder and select it directly in the Auralisation setup.

Microphone inverse filter for room acoustic measurements

This is useful for neutralizing the response of a microphone during measurements with ODEON's Sweep Measurement Facilities.

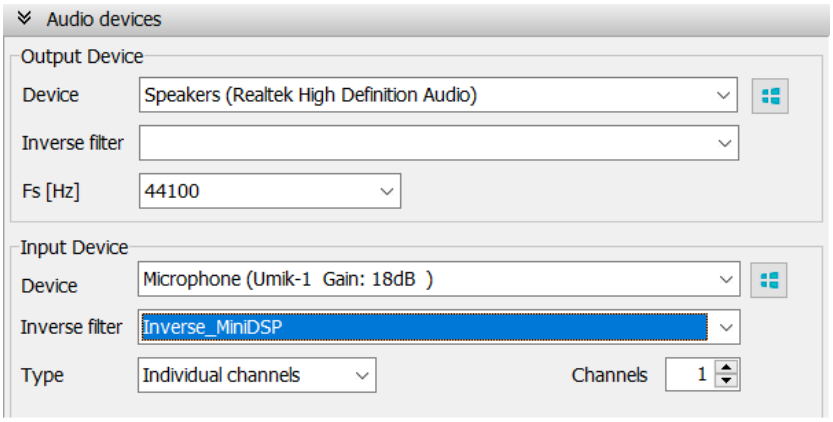
- Typically, the manufacturer of a professional microphone can supply a .txt file with the frequency response in two columns: 1st column containing the frequencies and 2nd column containing the response in dB.
- Use the .txt file to create the corresponding impulse response of the device with the Create impulse response file (.wav) from spectrum (.txt) tool.
- Create the inverse filter of the Impulse response by using the Create inverse filter (.wav) tool.
- Once you save the inverse filter file, make sure to press the Copy inverse filter button to copy the file in the Measurements filter folder.
- The inverse filter file should now be available under the Input divide settings in the ODEON's Sweep Measurement Facilities. See below.



Since version 17, ODEON comes with an example of .txt spectrum file, an impulse response and an inverse filter file, corresponding to UMIK, by MiniDSP microphone. They are all located in the *Measurements* folder.

Caution! The UMIK spectrum and Inverse filter files that come with the ODEON installation are only there for demonstration purposes, since they match a particular item, by the serial number. Therefore, they will not be as accurate if you attempt to apply to another UMIK item. In principle, you will have to

The exact same procedure can be followed for an output device as well, i.e. for a omni-directional loudspeaker used in measurements.


Audio devices
Output Device
Device
Speakers (Realtek High Definition Audio)
Inverse filter
Fs [Hz]
44100
Input Device
Device
Microphone (Umik-1 Gain: 18dB)
Inverse filter
Inverse_MiniDSP
Type
Individual channels
Channels
1

Appendix H: Modelling rooms in the ODEON Editor

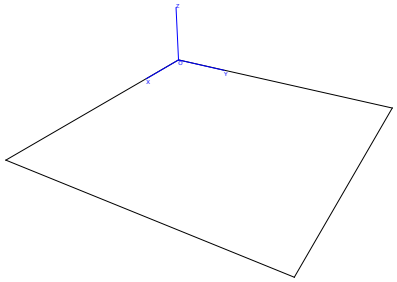
The ODEON .Par modeling format /language

Geometry models can be made using the parametric modelling language, which is built-in to ODEON. The model data is typed into a text file with the file extension .Par using the modelling language described below. You may use the supplied editor ODEONEdit to create and edit your text files. The ODEON modelling format is not case-sensitive, so upper and lower-case letters can be used as desired.

A simple modelling example

At its simplest (but not fastest), a floor with the dimensions 4 x 4 metres can be defined as follows (using the reserved keywords ***Pt*** and Surf in order to define points and surfaces):

```
FloorSurface.Par
###
Pt      1       0       0       0
Pt      2       4       0       0
Pt      3       4       4       0
Pt      4       0       4       0
Surf    1       floor
  1     2       3       4
###
```



One may choose to model the room point-by-point and surface-by-surface as in the example above. However, for many geometries, it will be an advantage to use parameters to describe basic dimensions in the rooms and to use high level statements to describe multiple points and surfaces in a fast and flexible way. Before starting your first large modelling project it is a very good idea to read through Chapter 3 or at least skim it - it will pay off in the end.

Another way to learn about the modelling language is to study the examples, which are installed in the \ODEON...\Rooms\Manual samples directory along with the ODEON program – open the room(s) in ODEON, then click the Open the ODEON Editor icon on the toolbar in order to study the geometry file.

Components in the modelling format

The basic function of the modelling format is to allow modelling of surfaces in room geometries. The surfaces can be modelled point-by-point, surface-by-surface, however it is also possible to make use of symmetry and to create repeated features in a room such as columns, using loops. Finally, it is possible to use hybrid functions, which create points as well as surfaces in terms of shapes such as boxes, cylinder and domes.

Constants, variables and counters

Constants and variables can be defined and used in the file format. It is a good habit to use constants whenever a value is used more than a few times in a file, this reduces typing errors and it also makes it easier to make general changes to geometry such as changing the height of a room.

Mathematical expressions

Mathematical expressions can be used to express any real or integer number in the file e.g. coordinates, constants, variables, counters, point numbers, surface numbers, etc. If you use a value

that is not an integer, to describe a point or surface number, then that value will be rounded to the nearest integer value.

You may describe coordinates using mathematical expressions like:

Length*Sin(PI/4)

where ***Length*** is a user-defined constant or variable. Mathematical expressions may not contain any SPACE or TAB (tabulation) characters. To get a complete overview of the mathematical functions available, please refer to Appendix J: Mathematical Expressions.

Points

A point is made up from a unique point number and its X,Y and Z coordinates. Use the ***Pt***, ***MPt*** and ***CountPt*** statements to define points. Points can also be defined implicitly, using one of the hybrid statements.

Surfaces

A surface is made up from a unique number, an optional descriptive text and a number of points connected to one another. All the points must be coplanar; otherwise the surface cannot be constructed. To define surfaces, use the ***Surf***, ***MSurf***, ***CountSurf***, ***ElevSurf***, ***ElevSurf2*** and ***RevSurf*** statements. Surfaces may also be defined implicitly using the hybrid statements.

Hybrid statements

Hybrid statements are: ***Box***, ***Cylinder***, ***Cylinder2***, ***Cone***, ***Dome***, ***Dome2*** and ***ElevSurf***. The hybrid statements create the points and surfaces needed to model the specified shape. The points and surfaces created must always have unique numbers.

Coordinate manipulation functions

A set of functions for coordinate manipulation (and surfaces made up from coordinates) is included. This includes rotation around the various axes, scaling and translation. These functions are needed in order to insert shapes defined by the hybrid statements in the geometry with the correct position and orientation.

Comments and empty lines

Lines containing comments, and empty lines, may be inserted anywhere in the file, as long as they do not come between data items, which should occur on one line. Comment lines must begin with a colon (:), a semicolon (;), a slash (/) or an asterisk (*). The semicolon can also terminate a non-comment line, allowing the non-comment line to be followed by a comment.

A series comment lines are started with a '{' and terminated by a '}' at any position on a line. This is useful to disable a section of lines.
Syntax highlighting in the ODEON editor makes it easy to spot comment lines.

Reserved keywords, predefined counters and constants
The following keywords are reserved by ODEON and have a special meaning in the parametric modelling language:

Line folding markers
BeginBlock, ***EndBlock***

Constant and variable statements
Const, ***Var***

Point statements
Pt, MPt, CountPt

Point list statements
Plist0 – Plist9
ResetPList0 – ResetPList9
PlistA, PListB

Surface statements
Surf, MSurf, RevSurf, CountSurf, ElevSurf, ElevSurf2

Hybrid statements
Box, Cylinder, Cylinder2, Cone, Dome, Dome2

Loop statements
For…End,

Transformation statements
Mreset, MPop, MScale, MTranslate, MRotateX, MRotateY, MRotateZ
*(*and for compatibility with earlier releases of ODEON: ***Scale, UCS)***

Predefined constants
PI = 3,14159265358979312

Predefined variables
NumbOffSet, ONVert

Predefined Counters
PtCounter

Coordinate system definition statements
Unit, CoordSys

Debugging Facilities
DebugIsOn, Debug

Line folding markers

Line folding is a feature of the ODEON editor where a section of lines (e.g. a part of the geometry) can be collapsed (folded) into one line in the editor for a better overview. This is the only functionality of the two keywords ***BlockBegin..BlockEnd***, they are ignored by ODEON when a .par file is loaded. The keywords are automatically generated when a room is generated by **ODEONExtrusionModeller** or when a room is imported in the .dxf format.

```
BeginBlock <optional comment>
        NumbOffSet 100
        Pt   1          0          -1         0
        Pt   2          0          1          0
        Pt   3          1          1          0
        Pt   4          1          -1         0

        Surf            1          A surface
             1          2          3
EndBlock <optional comment>
```

Any code between a corresponding set of *BlockBegin* and *BlockEnd* lines can be collapsed by clicking a small + in the left side of the editor, making it easier to handle large files, in particular with many layers. All blocks can be collapsed from the view menu in the ODEONEditor. And Blocks can be nested, that is, have Blocks contained within Blocks.

Defining constants

Constants must follow the syntax:

Const <Name> <Value>

where ***<Value>*** is a mathematical expression, which may be based on numbers or constants and variables that have already been defined.

Example 1:

```
Const       CeilingHeight       3.4
```

Example 2:

```
Const       FloorLevel          1
Const       CeilingHeight       FloorLevel+3
```

Example 3:

```
Const       FloorLevel          1
Const       Length              6
Const       CeilingHeight       FloorLevel+Length*TanD(30)
```

Defining and reassigning variables

The definition of variables must follow the syntax:

Var <Name> <OptionalValue>

Example 1; defining the variable ***FloorLevel***:

```
Var         FloorLevel
```

Example 2; defining the variable ***FloorLevel*** and assigning the initial value ***0***:

```
Var         FloorLevel          0
```

Example 3; reassigning a variable /adding 1 metre to the ***FloorLevel***:

```
FloorLevel FloorLevel+1
```

Remark: The predefined variable ***NumbOffSet*** may be used like any other variable, but has a special meaning because it offsets point and surface numbering. This variable is useful if copying a part of a geometry from another geometry file, it is also useful in connection with the ***for..end*** statements. ***Auto*** can also be assigned to ***NumbOffSet,*** in doing so ODEON will automatically increment the value of ***NumbOffSet*** to be greater than any point and surface number previously defined. This has the advantage that repeated point and surface numbers can easily be avoided without having to keep track on the numbers used - the drawback is that slight changes in the geometry file may change numbers on many subsequent surfaces, ruining the relationship between surface numbers and the material assigned to that surface inside the ODEON program. The ***Auto*** option is very useful in

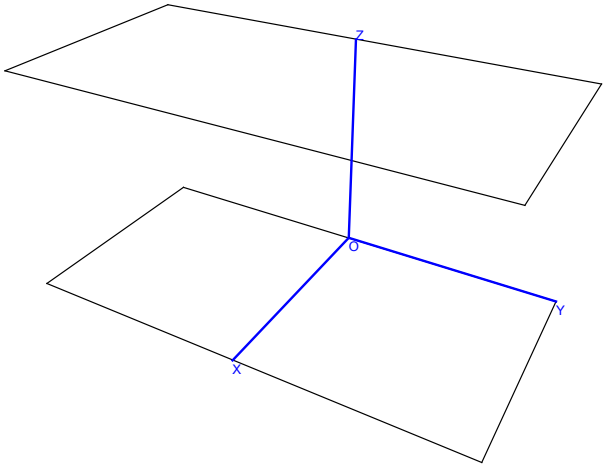
combination with loop constructions (see description of the ***for..end*** constructs later on). Typing ***PtAbsRef*** after the value assigned to ***NumbOffSet*** forces absolute number references for points while using the specified offset on the numbers of surfaces – this is explained later.

Example on the use of ***NumbOffSet***; creating surface 101 containing the points 101 to 104 and surface 201 containing the points 201 to 204:

```
NumbOffSet.Par
###
NumbOffSet 100
Pt          1          0          -1          0
Pt          2          0          1           0
Pt          3          1          1           0
Pt          4          1          -1          0

Surf        1          A surface
  1         2          3          4

NumbOffSet             NumbOffSet+100
Pt          1          0          -1          1
Pt          2          0          1           1
Pt          3          1          1           1
Pt          4          1          -1          1
Surf        1          Another surface
  1         2          3          4
###
```



Example creating points 1–4 and surface 1, setting ***NumbOffSet*** to ***Auto***, then creating Point 5-8 and surface 5:

```
###
Pt          1          0          -1          0
Pt          2          0          1           0
Pt          3          1          1           0
Pt          4          1          -1          0

Surf        1          A surface
  1         2          3          4

NumbOffSet             Auto
Pt          1          0          -1          1
Pt          2          0          1           1
Pt          3          1          1           1
Pt          4          1          -1          1
Surf        1          Another surface
  1         2          3          4
###
```

Defining a point using the Pt statement

Use the ***Pt*** statement to define a single point. The syntax must be as follows:

Pt <Point Number> <XMathExpression> <YMathExpression> <ZMathExpression>

Example defining point number 100 in (x,y,z) = (1,1,1):

```
Pt          100        1          1          1
```

Hint: Point number and coordinates can be written using mathematical expressions, allowing greater flexibility and reusability.

Parametric modelling – defining multiple points

Use the ***MPt*** statement to define a series of points, which is typically used in connection with the ***ElevSurf*** or ***ElevSurf2*** Statement. The syntax must be as follows:

MPt <Number> <NumberOfPoints>
<XMathExpression1> <YMathExpression1> <ZMathExpression1>
<XMathExpression2> <YMathExpression2> <ZMathExpression2>
....NumberOfPoints lines each defining a point in the multi point sequence, should follow the MPt statement.

<Number>
A unique number from 1 to 2.147.483.647 for identification of the first point in that multi point sequence.

<NumberOfPoints>
The number of points defined by this multipoint statement - if the number is 3, then 3 lines should follow, each describing the coordinates of a point.

Example 1; defining point number 100 in (x,y,z) = (1,1,1) and point number 101 in (x,y,z) = (2,2,2)

```
MPt  100 2
  1.0  1.0  1.0
  2.0  2.0  2.0
```

As a special option for multi points, it is possible to repeat a coordinate used in the previous point of that multipoint sequence or to repeat the coordinate while adding or subtracting a value from that point:

Example 2; defining point number 100 in (x,y,z) = (1,1,1) and point number 101 in (x,y,z) = (1,2,0)

```
MPt  100 2
  1  1  1
  =  =+1  =-1
```

Defining a series of points using the CountPt statement

The ***CountPt*** statement must follow the syntax:

CountPt<FirstPointNo><MaxCount><XMathExpression><YMathExpression><ZMathExpression>

Use the ***CountPt*** statement to define a series of points using a counter. This statement makes use of the predefined counter ***PtCounter***, which will run from ***0*** to ***MaxCount-1***, producing the points with the numbers ***FirstPointNo*** to ***FirstPointNo+MaxCount-1***. Use the ***PtCounter*** in the expression of the x,y and z coordinates to create the desired differences between the 'count points'.

Example; defining 7 points on a circle with a radius of 10 at Z=0 metres:

```
CountPt     100        6+1        10*CosD((PtCounter)*360/6)            10*SinD((PtCounter)*360/6)
  0
```

Note! First and last point in this series of 'count points' are equal (redundant). This will typically be desirable when using the ***CountPt*** statement along with ***RevSurf*** statement.

Defining a single surface using the Surf statement

A ***Surf*** statement is divided into two lines and must follow the syntax:

Surf <SurfaceNumber> <Optional Description>
<ListOfPointNumbers>

The ***Surf*** statement is used to define a single surface (in some situations with symmetry, two surfaces). The ***Surf*** statement is constructed from two lines, one identifying the surface by a number and an optional name and another with a list of corner numbers.

<SurfaceNumber>

A unique number from 1 to 2,147,483,647 for identification of the surface. Using the same number, but with negative sign defines the surface and its counterpart mirrored in the XZ-plane (Y = 0). The surface number may be defined using mathematical expressions.

<Optional Description>

A string displayed and printed for easy identification of the surface, i.e.: 'Main floor'.

<ListOfPointNumbers>

Each surface may be bounded by between 3 and 500 corners, which all lie in a plane. Corner numbers refer to the corners, which must have been defined (e.g. using the ***Pt*** or ***CountPt*** statements) before using the surface statement. The order of listing must be as obtained by travelling around the surface's perimeter (in either direction). The list of corner point numbers must be on the same line. A room may contain up to 10000 surfaces.

Example 1, surface made from point 1, 2, 3, 4:

```
Surf        100       floor
  1         2         3         4
```

Example 2, surface made from point 1,2,10,11,12,13,14,4,5:

```
Surf        200       Ceiling
  1         2         10>14     4         5
```

If there is a need to programmatically build a list of points, this can be done using the PList and ResetPList statements.

Building lists of points using PList and ResetPList

The ***PList*** and ***ResetPList*** statements are used in special cases together with the ***Surf*** statement. Twelve lists are predefined namely ***PList0*** to ***PList9*** (and ***PlistA*** and ***PListB*** which are handled automatically by ODEON when modelling a box and other solids). The ***PList*** statements allow to programmatically construct a list of points e.g. a list like:

```
100 110 120 130 140 150 160 170 180 190 200
```

this can be done using a ***for..end*** construct in the following way (adding a point number at a time):

```
for MyCounter 0 10
        PList0      100+MyCounter*10
end
```

It is also possible to add a number of points to a point list, e.g. another ***PList*** to a ***PList.*** In the following example ***PList1*** is assigned the points 100 110 120 130 140 150 160 170 180 190 200 10 11 12 13 15):

```
Plist1 Plist0 10>13    15
```

A point list can be referenced in the following way (adding point 1 before and 2 after the list in this example):

Surf Test_surface
1 PList0 2

To reset the list use the statement (list 0 used in this example):
ResetPList0

Multi Surface - MSurf

The multi surface ***MSurf*** is essentially just a variant of the ***Surf*** statement. Instead of typing one header line (e.g. ***Surf 1 A surface name***) for each surface, the header can be shared by multiple surfaces.

MSurf <SurfaceNumber> <NumberOfSurfaces> <Optional Description>
<ListOfPointNumbers1>
<ListOfPointNumbers2>
<ListOfPointNumbers3>
<NumberOfSurfaces> lines with lists of points describing each surface.

<SurfaceNumber>
A unique number from 1 to 2,147,483,647 for identification of the surface. Using the same number, but with a negative sign defines the surface and its counterpart mirrored in the XZ-plane (Y = 0). The surface number may be defined using mathematical expressions.

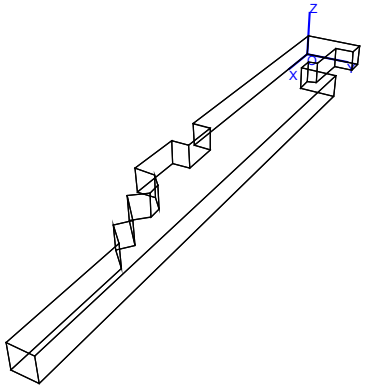
<NumberOfSurfaces>
The number of surfaces in the ***MSurf***.

<Optional Description>
A string displayed and printed for easy identification of the surfaces. Could be something like ***Main floor***.

Example on multi surface, containing 5 sub-surfaces:
MSurf 1 5 Steps on a stair
5544>5534 5112>5122
5111>5101 5212>5222
5211>5201 5312>5322
5311>5301 5412>5422
5411>5401 5512>5522

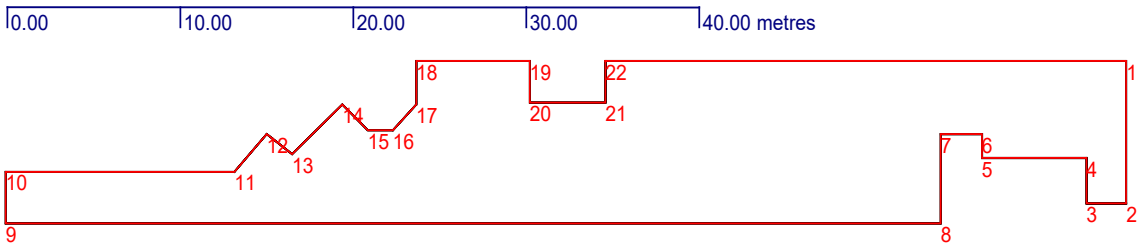
Elevation surface

Use the ***ElevSurf*** statement to define a series of vertical surfaces from a series of perimeter points plus an elevation height. The perimeter points are typically defined using the ***MPt*** statement. The syntax of ***ElevSurf*** is:



ElevSurf <FirstSurfaceNumber> <FirstPointNumber> <SectionsInElevSurf> <Height> <Optional name>

Example on use of the ***MPt*** and ***ElevSurf*** statements:
First the perimeter points (point 1 to 23) at the floor level of an office environment are described using the ***MPt*** statement. Then the elevation surface is created from these points, creating the perimeter walls of the office with a constant height of 2.7 metres. Finally, the floor and ceiling are created using the ***Surf*** statement.



Perimeter points at the floor level

Example file: MPt and ElevSurf.Par

Demonstrates the use of ***MPt*** (multi point), ***Surf*** (Surface) and ***ElevSurf*** (Elevation surface) statements. In this example the X-coordinates are expressed in absolute values whereas the Y-coordinates in most cases are increased or decreased using the =+ or =- operators, respectively.

To create a closed ***ElevSurf*** (that is, the first wall joins the last wall), the first and last point in the series of points handled to the ***ElevSurf*** must be identical - in this example, point 1 and point 23 are identical. If an elevation surface has 22 surfaces, then 23 points must be made available to the ***ElevSurf*** as in this example.

```
###
MPt 1 23
0 0 0
= 7.48 =
2.3 = =
= =-2.38 =
8.35 = =
= =-1.26 =
10.76 = =
= =+4.64 =
64.78 = =
= =-2.68 =
51.52 = =
49.62 =-2.02 =
48.22 =+1.1 =
45.3 =-2.68 =
43.85 =+1.45 =
42.40 = =
40.98 =-1.45 =
= 0 =
34.5 = =
= =2.1 =
30.13 = =
= =-2.13 =
0 0 0

ElevSurf 1 1 22 2.7 walls

Surf 200 Floor
1>22

Surf 201 Ceiling
24>24+22-1
###
```

Elevation surface 2

Use the *ElevSurf2* statement to define a series of vertical surfaces from a series of perimeter points plus an elevation height. The perimeter points are typically defined using the *MPt* statement. The syntax of *ElevSurf2* is:

ElevSurf2 <FirstSurfaceNumber> <FirstPointNumber> <SectionsInElevSurf> <Height> <T/B/N> <Optional name>

The *ElevSurf2* only differs from *ElevSurf* in that a top and bottom surface may be specified (the T/B/N option).

<FirstSurfaceNumber>

A unique number from 1 to 2,147,483,647 for identification of the first surface in the *ElevSurf2* surface. Using the same number, but with negative sign, defines the surfaces and their counter parts mirrored in the XZ-plane (Y = 0).

<FirstPointNumber>

First point number in the floor perimeter. The floor points are typically *MPt* statement. See example below.

<SectionsInElevSurf>

The number of surfaces to be created by the *ElevSurf2* statement. If creating a cylinder, a number between 16 and 24 is suggested (if it's a column, use only six to eight surfaces).

<Height>

Height is oriented in the Z-direction.

<T/B/N>

The *T/B/N* parameter specifies whether the *ElevSurf2* should have a top and /or a bottom. The options are *T*, *B*, *TB* and *N* (for none). Top or bottom may only be included if all of the points in the floor in the elevation surface are in the same plane.

Example on use of the MPt and ElevSurf2 statements.

First the perimeter points (points 1 to 23) at the floor level of an office environment is described using the *MPt* statement. Then the elevation surface is created from these points, creating the perimeter walls of the office with a constant height of 2.7 metres.

In this example the X-coordinates are made in absolute values whereas the Y-coordinates in most cases are increased or decreased using the =+ or =- operators, respectively.

To create a closed *ElevSurf2* (that is, the first wall joins the last wall), the first and last point in the series of points handled to the *ElevSurf2* must be identical - in this example, point 1 and point 23 are identical.

If an elevation surface has 22 surfaces, then 23 points must be made available to the *ElevSurf2* as in this example.

```
###
MPt 1 23
0 0 0
= 7.48 =
2.3 = =
= =-2.38 =
8.35 = =
= =-1.26 =
10.76 = =
= =+4.64 =
64.78 = =
= =-2.68 =
51.52 = =
49.62 =-2.02 =
```

48.22 =+1.1 =
45.3 =-2.68 =
43.85 =+1.45 =
42.40 = =
40.98 =-1.45 =
= 0 =
34.5 = =
= =2.1 =
30.13 = =
= =-2.13 =
0 0 0

ElevSurf2 1 1 22 2.7 TB walls
###

Defining a number of surfaces using the CountSurf statement

The ***CountSurf*** is mostly available for backwards compatibility. In most cases it will be easier to use the ***Surf*** statement along with a ***for….end*** loop.
A Counter surface is divided on two lines and must follow the syntax:

CountSurf <First Surface Number> <NumberOfSurfaces> <Optional name>
<ListOfPointNumbers>

<FirstSurfaceNumber>
A unique number from 1 to 2,147,483,647 for identification of the surface. Using the same number, but with negative sign defines the surface and its counterpart mirrored in the XZ-plane (Y = 0). A ***CountSurf*** will take up several surface numbers, which must all be unique.

<NumberOfSurfaces>
The number of surfaces to be created by the ***CountSurf*** call.

<Optional name>
Optional user defined name for easy identification of the surface, e.g. 'Beam'.

<ListOfPointNumbers>
Each surface may be bounded by between 3 and 50 corners, which all lie in a plane. Point numbers refer to the corners, which must have been defined (e.g. using the ***Pt*** or ***CountPt*** statement) before using the surface statement. The order of listing must be as obtained by travelling around the surface's parameter (in either direction). The list of corners must be on the same line of code. A room may contain up to 10000 surfaces.

Example:

```
CountSurf  1000     5       Beam in ceiling
           1000     1100    1200     1300
```

will produce five surfaces, the first one containing the numbers given in the ***ListOfPointNumbers***, and the next surface with 1 added to all the corners in the list, etc. Of course, all the points referred to need to be defined, typically this is done using a ***CountPt*** definition for each of the corners referred to in the corner list of the ***CountSurf*** statement. In the above example the points 1000-1004, 1100-1104, 1200-1204 and 1300-1304 need to be defined.

Sample room files:
Beams.Par
BeamBox.Par
BeamBoxWithWindows.Par

Revolution surface RevSurf

RevSurf must follow the syntax:

RevSurf <FirstSurfaceNumber> <CurveStart1> <CurveStart2> <SectionsInRevSurf> <Optional name>

The ***RevSurf*** command is typical used together with two ***CountPt*** statements to create a revolution surface using two 'curves' of points. The curves must contain the same number of points. The ***RevSurf*** command will always create a number of surfaces each build from four points.

<FirstSurfaceNumber>

A unique number from 1 to 2,147,483,647 for identification of first surface in the revolution surface. Using the same number, but with negative sign, defines the surface and its counterpart mirrored in the XZ-plane (Y = 0).

<CurveStart1>

First point number in the first revolution curve. The 'curve of points' is typically created using the ***CountPt*** statement and the curve must contain one more point than number of sections in the ***RevSurf***.

<CurveStart2>

First point number in the second revolution curve. The curve of points is typically created using the ***CountPt*** statement and the curve must contain one more point than the number of sections in the ***RevSurf***. The second curve must always contain the same number of points as the first curve.

<SectionsInRevSurf>

The number of surfaces to be created by the ***RevSurf*** statement. If creating a cylinder, a number between 12 and 24 is suggested. Although it is easy to create many surfaces in a revolution surface, too many small surfaces should be avoided. If the ***FirstSurfaceNumber*** is 100 and ***SectionsInRevSurf*** is 3, surfaces 100, 101 and 102 will be created.

<Optional name>

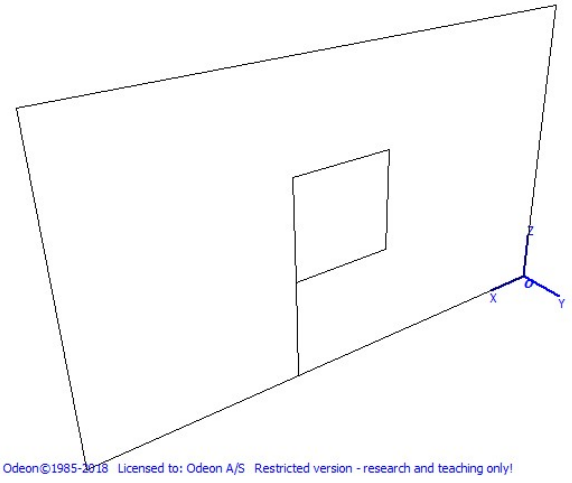
Optional user defined name for easy identification of the surface, e.g. 'cylindric wall'.

Example:

RevSurf 1000 100 200 6 Cylinder

creates a revolution surface divided in 6 surfaces (surface 1000 - 1005). This call requires two curves of each 6+1 points to be defined, namely point 100 to 106 and point 200 to 206. If the two curves of points define corners in the lower and upper edge of a cylinder, a cylinder of 6 sections is created (see example room: RevSurfCylinder.Par)

Loop surface <LSurf>



LSurf must follow the syntax:

LSurf <FirstSurfaceNumber><NumberOfLoops><Optional name>
<ListOfPointNumbers1>
<ListOfPointNumbers2>
<ListOfPointNumbers3>
<NumberOfSurfaces> lines with lists of points describing each loop - the first line preferably being the outer loop

The *LSurf* command is typical used for creating walls with window holes in them. In the special case where NLoops is equal to 1 the surface is identical to that created using the Surf command.

<FirstSurfaceNumber>

A unique number from 1 to 2,147,483,647 for identification of the first surface in the *LSurf* surface. Using the same number, but with negative sign, defines the surface and its mirrored counterpart in the XZ-pane (Y = 0).

<NumberOfLoops>

A least 1 for the outer perimeter of the surface. If e.g 3 then there is to addiotional loops describing 2 holes (e.g. windows in the surface). In order to close the holes in the surfaces additional surfaces has to be added e.g.using the Surf command.

<Optional name>

Optional user defined name for easy identification of the surface, e.g. 'cylindrical wall'.

Example

```
Pt   1   0   0   0
Pt   2   5   0   0
Pt   3   5   0   3
Pt   4   0   0   3
Pt   5   2   0   1
Pt   6   3   0   1
Pt   7   3   0   2
Pt   8   2   0   2

LSurf   1   2   Wall with a window hole
  1   2   3   4
  5   6   7   8
```

... creates an LSurf with the outer perimeter defined by points 1-4, and a hole defined by points 5-8.

Loops using the FOR....END construct

The ***For*** statement must follow the syntax:

For <CounterName> <CountFrom> <CountTo>

<CounterName>

Name of counter to be used by the ***For*** statement. The counter is automatically defined by the ***For*** statement and becomes undefined when the loop finishes. The counter can be referenced within the ***for..end*** loop as an ordinary constant or variable if desired so.

<CountFrom>

First value the counter takes. The ***CountFrom*** value is considered an integer value. If the number entered here is not an integer, it will be rounded to the nearest integer value.

<CountTo>

Last value the counter takes. The ***CountTo*** value must be greater or equal to the ***CountFrom*** value. The ***For*** statement will take ***CountTo-CountFrom+1*** loops. The ***CountTo*** value is considered an integer value, if the number entered here is not an integer, it will be rounded to the nearest integer value.

The following example will produce the points 1 to 5 with the X-coordinates 5, 10, 15, 20 and 25 metres, while the counter (***MyCounter***) loops through the values 1 to 5:

```
For MyCounter      1          5
  Pt        MyCounter        MyCounter*5      0          0
end
```

When using ***For..End*** constructs, it should be remembered that point and surface numbers must be unique. This is easily obtained by incrementing the special variable ***NumbOffSet*** appropriately in each loop. An example on this kind of numbering can be found in the sample file BoxColumnRoom.Par where ***NumbOffSet*** is incremented by eight in each loop (each time a new column, which contains 4 surfaces and 8 points, is created).

Sample room files:

ForRotunde.Par
BoxColumnRoom.Par

Unit

The ***Unit*** statement is used if you wish to model in a unit different from metres. The unit used in the parametric file is by default assumed to be metres, however if you prefer to model in another unit, this is possible using the ***Unit*** statement.

Example, modelling in Inches:

```
Unit  Inches
```

You may choose your unit among the following predefined:

Metres, Centimetres, Millimetres, Inches, Feet and Yards

Or if you need a different unit, simply type the scaling factor from your unit into metres, e.g.

```
Unit Inches
```

corresponds to:

```
Unit   0.0254
```

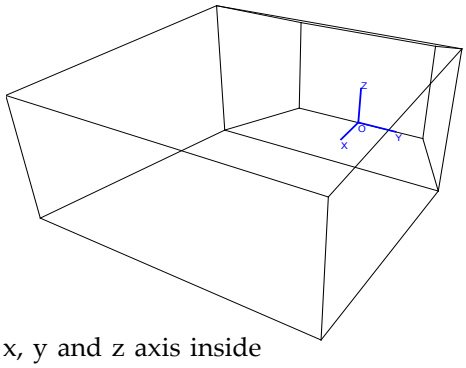
The ***Unit*** statement may be used more than once in the same .par file:

```
###
Unit Inches
;e.g. imported model data in inches
.....model data.......
.....model data.......
Unit 0.57634
; model data measured on a paper drawing which appeared in an odd unit
```

.....model data.....
.....model data.....
Unit Metres
; model data appended in the ODEON editor / modelling environment
;it is most practical to use metres as the unit when modelling in the ODEON
;environment - then coordinate values will be the same in the Editor as inside the 3D View in ODEON
.....model data.....
.....model data.....
###

CoordSys statement

The ***CoordSys*** statement is used if you wish to redefine the orientation or the coordinate system in which the geometry was modelled. The statement is typically used if the geometry was 'by accident' modelled in an orientation different from the one assumed by ODEON or if it was imported from a CAD drawing where the orientation may also be different. To obtain the easiest operation inside ODEON the following orientation should be used (using a concert hall as the example):



- X-axis pointing towards the audience
- Y-axis pointing to the right as seen from the audience
- Z-axis pointing upwards

The syntax is:

CoordSys <X> <Y> <Z>

where X, Y, Z indicate which axis should be used as the x, y and z axis inside ODEON. X, Y and Z may also have a sign to indicate that the axis should point in the opposite direction.

Example 1, the default orientation (which is assumed by ODEON if the ***CoordSys*** statement is not used in the geometry file):

CoordSys X Y Z

Example 2, changing the direction of the X-axis:

CoordSys -X Y Z

Example 3, Swapping the X and the Z-axis

CoordSys Z Y X

Example 4, The *CoordSys* statement may be used more than once in the same .par file:

###
CoordSys -X Y Z
;e.g. if the X axis was inverted in imported model data
.....model data.....
.....model data.....
;resetting the coordinate system to the default
CoordSys X Y Z
; model data appended in the ODEON editor / modelling environment
;it is most practical if using the default Coordinate system when modelling in the ODEON ;environment - then coordinate system will have the same orientation in the ODEON editor as well as in the 3D View inside ODEON.
.....model data.....
.....model data.....
###

User coordinate system

The ***UCS*** command is mostly there for compatibility with previous versions of ODEON – the coordinate manipulation functions ***MTranslate***, ***MRotateX***, ***MRotateY***, ***MRotateZ***, ***MScale***, ***MPop*** and ***MReset*** included from version 4.21 allow far more flexibility. For your own convenience, it is not advisable to mix the ***UCS*** method with the ***M***-family method.
The ***UCS*** command must follow the syntax:

UCS <TranslateX><TranslateY><TranslateZ><RotateZ>

The ***UCS*** command is used to create a User Coordinate System, with its own X, Y and Z translation. It also allows a rotation around the Z-axis (specified in degrees). All point definitions made after a ***UCS*** call will be created in the specified coordinate system. The default coordinate system is defined as:

UCS 1 1 1 0

The ***UCS*** command corresponds to:

MReset
MTranslate <TranslateX><TranslateY><TranslateZ>
MRotateZ <RotateZ>

If the ***UCS*** command doesn't fulfill your needs for coordinate manipulation, you may use the matrix manipulation family ***MTranslate***, ***MRotateX***, ***MRotateY***, ***MRotateZ***, ***MScale***, ***MPop*** and ***MReset.***

Scale

The ***Scale*** command is mostly there for compatibility with previous versions of ODEON – the coordinate manipulation functions ***MTranslate***, ***MRotateX***, ***MRotateY***, ***MRotateZ***, ***MScale***, ***MPop*** and ***MReset*** included from version 4.21 allow far more flexibility. For your own convenience, it is not advisable to mix the ***Scale*** method with the ***M***-family method.

The ***Scale*** command must follow the syntax:

Scale <ScaleX><ScaleY><ScaleZ>

The scale command will multiply/scale all the points generated after the scale call, using the specified x, y and z-scale. The default setting is:

Scale 1 1 1

The ***Scale*** command evokes scaling of coordinates after all other coordinate manipulation is carried out. If you require more advanced scaling options, you may use the ***MScale*** option.

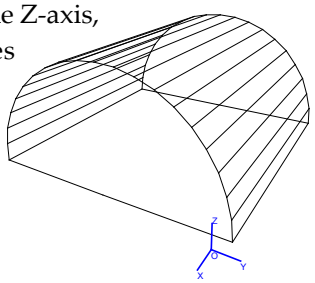
Coordinate manipulations – the M-family

Advanced coordinate manipulation can be carried out using matrix manipulation. The coordinate manipulation functions, which is essential to the use of hybrid statements (***Box***, ***Cylinder***, etc.) is implemented as the following functions:

MTranslate <TranslateX><TranslateY><TranslateZ>
MRotateX <Rotation angle>
MRotateY <Rotation angle>
MRotateZ <Rotation angle>

MScale <ScaleX><ScaleY><ScaleZ>
MPop
MReset

The manipulations carried out by the M-family are cumulative. This means that you can specify more than one operation to be carried out, e.g. first rotate 90° around the Z-axis, then rotate 90° around the Y-axis and finally translate 10 metres upwards. The following example shows these operations carried out on a cylinder shell (the ***Cylinder*** statement is described later):



```
Manipulating a cylinder.Par
###
MRotateZ  90
MRotateY  90
MTranslate          0        0        10
Cylinder   1         20       5        180      10                TB Cylindrical ceiling
###
```

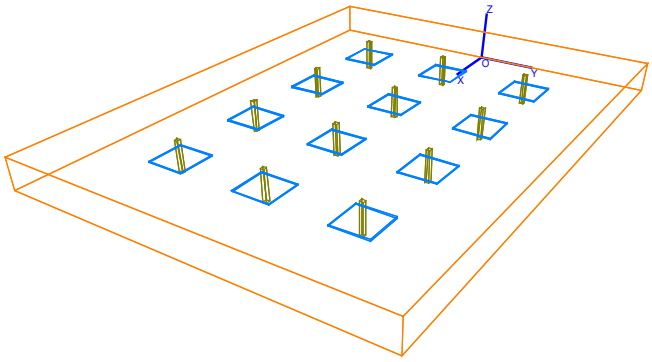
The transformation commands to be carried out must always be stated before the points/geometry on which they should work is created. To reset all previous coordinate manipulations, use the ***MReset*** command. To reset/cancel the most recent manipulation (***MTranslate*** in the example above), use the ***MPop*** command (which will pop the operation of the matrix stack).

Hints!

The order in which the coordinate manipulations are carried out is important: usually (but not necessarily always), the ***MScale*** commands should come first, then the ***MRotate*** commands and finally the ***MTranslate*** commands.
If you are not familiar with coordinate manipulations, it may be a good exercise to try different manipulations on the sample geometry above and load the geometry into ODEON upon each change.

Using layers in ODEON

The ***Layer*** statement allows dividing geometry into separate parts, which can be displayed separately and in its own layer-colour in the 3D View, 3D Render and Materials list. This makes it easier to model and investigate selected groups of surfaces. When importing geometry from a .dxf file (e.g. from AutoCAD where layers are an integrated part) the layers included in that file will be preserved in the imported version of the room.



If layers have been used in geometry, the layer can be activated or deactivated in the 3D View, 3D Render and Materials list. The layers menu is activated from these windows using the Ctrl+L shortcut.

Vocabulary – what's a layer?

Layers are commonly used in CAD modelling programs such as AutoCAD in order to make complicated geometries more easily manageable. Layers in CAD programs (and some drawing and picture editing programs) can be compared to overhead sheets (without any thickness). You define a number of layers with different names (and possibly different line colour/thickness etc.) and draw the different parts of your geometry on the different layers. The layers can be turned on or off in

the CAD program allowing better overview by hiding parts of the geometry that are not relevant in a part of the 'drawing' process.

Syntax for the Layer statement:

Layer <"Layer name in quotes"> <R-intensity><G-intensity><B-intensity>

or as another option:

Layer <"Layer name in quotes"> <LayerColour>

<"Layer name in quotes">
A name which must start and end with a quote sign (").

<R-intensity><G-intensity><B-intensity>
Three floating-point values between 0 and 1, which together is describing the colour of the layer as a Red-Green-Blue intensity. If using the Layer command Shift+Ctrl+L from within the ODEON editor, the colour intensities are set by clicking the desired colour in a dialog-box. Do note that it's not advisable to choose a greyish colour as it may not be easily visible in ODEON.

<LayerColour>
As another option the colour of the layer can be described, using one of the predefined colours ***Black, Blue, Cream, Fuchsia, Gray, Green, Lime, Maroon, Navy, Olive, Purple, SkyBlue, Teal, MoneyGreen or White***. The LayerColours.par example demonstrates the different colours.

The LayerStatement.par example shows how to create a geometry on three different layers.

Selected surfaces can be selected for display in the 3D View, 3D Render and the Materials list.

```
LayerStatementRoom.Par
###
const L 40
const W 30
const H 3
const NumColX 4
const NumColY 3
const ColumnW 0.3

MTranslate l/2 0 0
Layer "Walls" 1.000 0.502 0.000  ;orange colour
 Box 1 l w h tb walls in the room
 MPop
 :modelling the columns

for ColYCnt 1 NumColY
 for ColXCnt 1 NumColX
 MReset
 MTranslate ColXCnt*L/(NumColX+1) w/2-ColYCnt*W/(NumColY+1) 0

 NumbOffSet Auto
 Layer "Columns" 0.502 0.502 0.000
 Box 1 ColumnW ColumnW h n columns in the room ;olive colour
 NumbOffSet Auto
 MTranslate 0 0 1.2
 Layer "Table plates" 0.000 0.502 1.000 ;bluish colour
 Box 1 3 3 0.1 tb tables
 end
end
###
```

Symmetric modelling

Symmetric rooms can be modelled, taking advantage of the ODEON convention for symmetric models. This allows generation of symmetric or semi-symmetric rooms with symmetry around the XZ-plane, (Y = 0) – symmetric modelling is always carried out in the main coordinate system, it does not take into account manipulations carried out using ***UCS*** and ***MTranslate***. Modelling a surface as symmetric around the main axis' (e.g. a reflector above the stage) can be done using symmetric points. Modelling left and right walls at the same time can be done using a symmetric double surface.

Symmetric points

Surfaces symmetric around the XZ-plane, Y= 0 can be made using symmetric points. If defining the point:

```
Pt          2                   1.0       1.0       1.0
```

in the geometry file, using the point -2 in a surface definition of the geometry file will refer to the auto generated point:

```
Pt          -2                  1.0       -1.0      1.0
```

Thus the following surface definition:

```
Surf        1000 Symmetric surface
  1         2         -2        -1
```

will model a surface symmetric around the XZ-plane, Y=0 (e.g. an end wall or a reflector).

If the surface is completely symmetric as above, then the symmetric points can also be specified using the Mirror word, which should be the last component in the corner list:

```
Surf        1000 Symmetric surface
  1         2         Mirror
```

Note: You should not try to define the point -2 in the geometry file, as it is automatically generated.

Symmetric double surface

Symmetric double surfaces are pairs of surfaces symmetric around the XZ-plane, Y= 0 (e.g. a right and a left wall):

```
Surf        -2        Right wall/ Left wall
  12        22        23        13
```

will appear as two surfaces inside the ODEON program. Thus, you will have the following two surfaces (inside the ODEON program):

```
-2          Right/ Left wall
```

containing the symmetric points:

```
-12         -22       -23       -13
```

and the surface:

```
2           Right/ Left wall
```

containing the points:

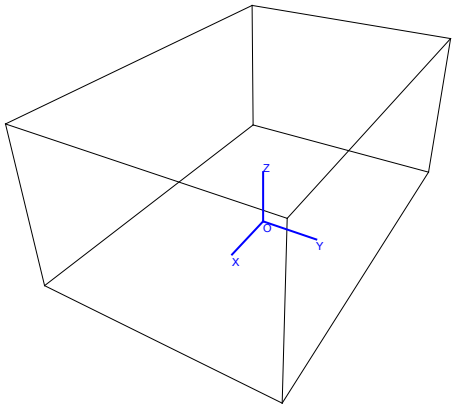
12 22 23 13

as they are defined in the geometry file.

Note: You may not define surface 2 if you are using the symmetric double surface -2, because ODEON automatically generates surface number 2.

The Box statement

The ***Box*** statement defines a Box with or without top and bottom. The ***Box*** statement may typically be used for Box-shaped rooms and columns. A special case of the Box statement is when one of the dimensions ***Length***, ***Width*** or ***Height*** is zero; in this case only one surface is created.



The syntax of the ***Box*** statement is:

Box <Number> <Length> <Width> <Height> <T/B/N>
<optional name>

<Number>

A unique number from 1 to 2,147,483,647 for identification of the first point and surface in the ***Box***. Using the same number, but with negative sign defines the box and its counterpart mirrored in the XZ-plane (Y = 0). A Box will take up several point- and surface numbers, which must all be unique.

<Length>

Length is oriented in the X-direction on the Figure.

<Width>

Width is oriented in the Y-direction on the Figure.

<Height>

Height is oriented in the Z-direction on the Figure.

<T/B/N>

The ***T/B/N*** parameter specifies whether the ***Box*** should have a top and /or a bottom. The options are ***T***, ***B***, ***TB*** and ***N*** (for none).

Insertion point:

The insertion point of the Box is always the centre of the floor (bottom) surface.

Connection points:

The four foot-points in ***Box*** are stored in ***PListA***
The four top-points in ***Box*** are stored in ***PListB***

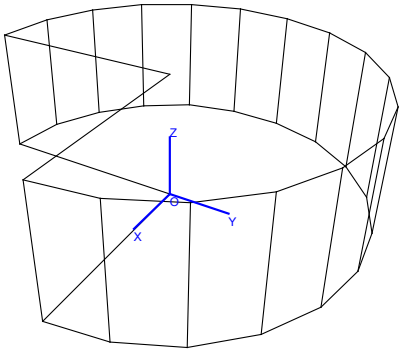
The ***Box*** example shown was generated with the following code:

BoxStatement.par
###
const L 6
const W 4

const H 2.7

Box 1 L W H TB Walls, floor and ceiling
###

The Cylinder statement



The ***Cylinder*** statement defines a cylinder shell with or without top and bottom. The statement may typically be used for modelling cylindrical room or columns. The ***Cylinder2*** statement, which creates a cylinder of the calotte type, will usually be preferable for modelling cylindrical ceilings.

The syntax for Cylinder is:

Cylinder <Number> <NumberOfSurfaces> <Radius> <RevAngle> <Height> <T/B/N> <optional name>

<Number>
A unique number from 1 to 2,147,483,647 for identification of the first point and surface in the ***Cylinder***. Using the same number, but with negative sign defines the cylinder and its mirrored counterpart in the XZ-plane (Y = 0). A Cylinder will take up several point- and surface numbers, which must all be unique.

<NumberOfSurfaces>
For a full cylindrical room (with a revolution angle of 360°), around 16 to 24 surfaces are recommended. For columns, a number between 6 to 8 is recommended.

<Radius>
Radius of the cylinder must always be greater than zero.

<RevAngle>
RevAngle must be within the range +/-360° and different from zero. If ***RevAngle*** is 180°, a half cylinder is generated, and if it's 360°, a full cylinder is generated. Positive revolution angles are defined counter-clockwise.

<Height>
If the height is less than zero, the orientation of the cylinder is inverted. If height is zero, one circular surface is generated.

Insertion point:
The insertion point of the cylinder is always the centre of the floor (bottom) surface.
Connection points:
The foot-points in ***Cylinder*** are stored in ***PListA***
The top-points in ***Cylinder*** are stored in ***PListB***

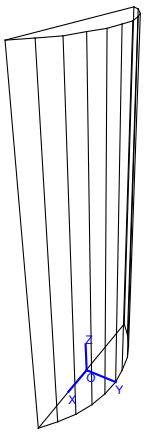
The example shown was generated with the following code:

CylinderStatement.Par
###
const N 16
const R 15
const H 10

Cylinder 1000 N R 270 H TB Cylindrical room
###

Hint! The cylinder can be made elliptical, using the ***MScale*** statement.

The Cylinder2 statement



Cylinder2 is a cylinder shell of the calotte type. Rather than specifying the radius and revolution angle, ***Cylinder2*** is specified in terms of the ***width*** and ***height***. ***Cylinder2*** is typically used for cylindrical /curved ceilings.

The syntax for Cylinder2 is:

Cylinder2 <Number> <NumberOfSurfaces> <Width> <Height> <Length> <T/B/N> <optional name>

<Width>

Width is oriented in the X direction on the Figure.

<Height>

Height of the cylinder shell is oriented in the Y direction on the Figure and may be positive (concave shell) as well as negative (convex shell). ***Height*** must be different from zero and less or equal to ½****Width***.

<Length>

Length of the cylinder shell is oriented in the Z direction the Figure. If ***Length*** is negative the orientation is inverted.

Insertion point:

The insertion point of ***Cylinder2*** is always foot point of the calotte floor (bottom) surface.

Connection points:

The foot-points in ***Cylinder2*** are stored in ***PListA***
The top-points in ***Cylinder2*** are stored in ***PListB***

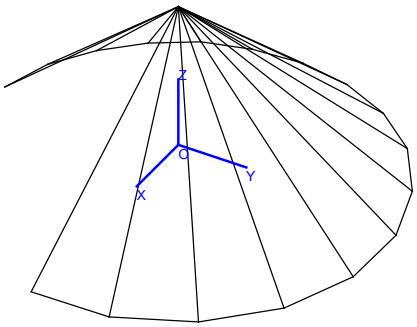
The example shown was generated with the following code:

```
###
Const N 10
Const W 5
Const H 1
Const L 10

Cylinder2 1 N W H L TB Cylinder calotte
###
```

Hint! The cylinder can be made elliptical, using the ***MScale*** statement.

The Cone statement



The ***Cone*** statement models a cone. Typical use of the ***Cone*** statement is for modelling half cone or cone shaped ceilings.

The syntax for ***Cone*** is:

Cone <Number> <NumberOfSurfaces> <Radius> <RevAngle> <Height> <optional name>

<Number>

A unique number from 1 to 2,147,483,647 for identification of the first point and surface in the Cone. Using the same number, but with negative sign defines the surface and its mirrored counterpart in the XZ-plane (Y = 0). A Cone will take up several point- and surface numbers, which must all be unique.

<Radius>

Radius of the Cone must always be greater than zero.

<RevAngle>

RevAngle must be within the range +/-360° and different from zero. If ***RevAngle*** is 180°, a half-cone is generated, and if it's 360°, a full cone is generated. Positive revolution angles are defined counter-clockwise.

<Height>

The height must be different from zero. If the height is less than zero, the orientation of the cone is inverted. Height is oriented in the Z-direction on the Figure.

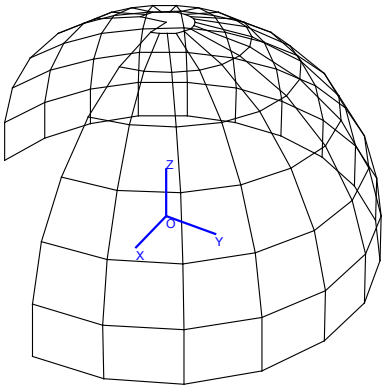
The ***Cone*** example shown was generated with the following code:

```
###
const N 16
const R 15
const H 10

Cone 1 N R 270 H Cone shaped ceiling
###
```

Hint! The cone can be made elliptical, using the ***MScale*** statement.

The Dome statement



The ***Dome*** statement generates a full dome (half hemisphere) covering the full 90° vertical angle. In most cases the ***Dome2*** statement is probably better suited.

The syntax for ***Dome*** is:

Dome <Number> <NumberOfSurfaces> <Radius> <RevAngle>
<optional name>

<Number>

A unique number from 1 to 2,147,483,647 for identification of the first point and surface in the ***Dome***. Using the same number, but with negative sign defines the dome and its mirrored counterpart in the XZ-plane (Y = 0). A ***Dome*** will take up several point and surface numbers, which must all be unique.

<Radius>

Radius of the ***Dome*** must always be greater than zero.

<RevAngle>

RevAngle must be within the range +/-360° and different from zero. If ***RevAngle*** is 180°, a half ***Dome*** is generated, and if it's 360°, a full ***Dome*** is generated. Positive revolution angles are defined counter-clockwise.

Connection points:

The right-side vertical points in ***Dome*** are stored in ***PListA***
The left-side vertical points in ***Dome*** are stored in ***PListB***
In the special case where the revolution angle is 180°, all points are stored in ***PlistA*** and the number of vertical subdivisions is stored in ***ONVert.***

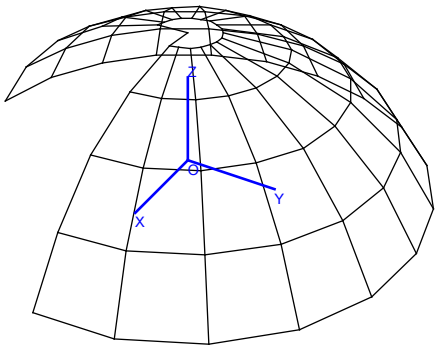
The example shown was generated with the following code:

```
###
const N 16
const R 15

Dome 1 N R 270 This is a dome
###
```

Hint! The dome can be made elliptical, using the ***MScale*** statement.

The Dome2 statement



The ***Dome2*** statement is a Dome shell of the calotte type, where the vertical revolution angle is not necessarily 90°. Rather than specifying the dome by a revolution angle, it is specified by the width and height. ***Dome2*** may typically be used for modelling dome shaped ceilings.

The syntax for ***Dome2*** is:

Dome2 <Number> <NumberOfSurfaces> <Width> <Height> <RevAngle> <optional name>

<Number>
A unique number from 1 to 2,147,483,647 for identification of the first point and surface in the dome. Using the same number, but with negative sign defines the surface and its mirrored counterpart in the XZ-pane (Y = 0). A dome will take up several point- and surface numbers, which must all be unique.

<NumberOfSurface>
Specifies the number of surfaces in one horizontal ring of the dome, around 16 to 24 surfaces per ring is suggested. ODEON will automatically calculate the number of subdivisions in the vertical level. If the revolution angle is 180° the number is stored in the ***ONVert*** variable, which would have been 9 in the example above. The ***ONVert*** variable may help when connecting a ***Dome2*** to a ***Cylinder2*** in order to specify the correct number of surfaces in the cylinder.

<Width>
Width at the beginning of the dome. The width must always be greater than zero.

<Height>
The ***Height*** must be different from zero. If the height is less than zero, the orientation of the dome is inverted. ***Height*** must be different from zero and less or equal to ½*****Width***.

<RevAngle>
RevAngle must be within the range +/-360° and different from zero. If ***RevAngle*** is 180°, a half-dome is generated, and if it's 360°, a full dome is generated. Positive revolution angles are defined counter-clockwise.

Connection points:

The right-side vertical points in ***Dome2*** are stored in ***PlistA***
The left-side vertical points in ***Dome2*** are stored in ***PlistB***

In the special case where the revolution angle is 180°, all points are stored in ***PlistA*** and the number of vertical subdivisions is stored in ***ONVert.***

The example shown was generated with the following code:

```
###
Const N 16
Const W 10
Const H 3
Const L 10

Dome2 1 N W H 270 Dome calotte
###
```

Hint! The cylinder can be made elliptical, using the ***MScale*** statement.

DebugIsOn and Debug

The debug options are useful when creating large or complicated geometries in the ODEON *.par* format. Using these facilities can speed up geometry loading when loaded for preview only and allow debugging of parameter values in geometry files. *DebugIsOn* is a Boolean, which can be set to *TRUE* or *FALSE*, the syntax is:

DebugIsOn <Boolean>

Typically, you will insert the *DebugIsOn* flag in the beginning of the geometry file in order to investigate parameter values, when loading geometry. When this Boolean is set to *TRUE*:

- ODEON will not prepare the geometry for calculation - as result the loading of rooms is sped up.
- ODEON will enable debugging of parameters with the *Debug* statement.

The syntax for *Debug* is:

Debug <debug string>

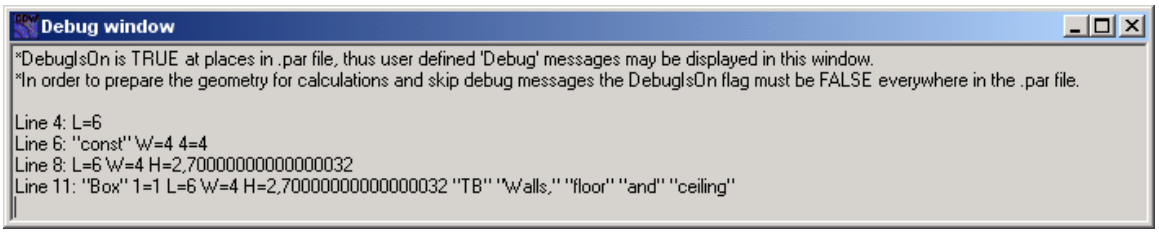
In effect, anything can be put after the *Debug* keyword, i.e. you may put a complete copy of a line in the *.par* file there. The contents following the *Debug* keyword is evaluated or if it can't be evaluated, it is echo'ed directly to the debug window in ODEON when loading the geometry and it has no effect on the geometry. If *DebugIsOn* is set to *FALSE*, then debug lines are ignored. Contents in the *Debug* strings, which cannot be evaluated, are displayed in quotes (").

Example: When loading the following .par *file into ODEON:*

```
###
DebugIsOn TRUE ;debug option turned on - if DebugIsOn is set to false then Debug lines are ignored
const L 6
Debug L ;debug a single constant
const W 4
Debug const W 4
const H 2.7
Debug L W H ; Debug values of L, W and H

Box 1 L W H TB Walls, floor and ceiling
Debug Box 1 L W H TB Walls, floor and ceiling ; Debug a complete line
###
```

ODEON will create this *Debug* window as a response:



Creating a new .Par file - time saving hints

The golden rule when creating a .Par file to model a room is to think carefully before you start typing. For very simple rooms, it is not too difficult to keep track of things, but for realistically complex rooms a systematic approach is desirable. You will typically have a set of drawings, which have to be used as the basis for the ODEON model. It pays to spend quite a long time working out how the room can be simplified to a manageable number of sensibly shaped plane surfaces, sketching over the drawings. These ideas will have to be modified when you start to work out the actual coordinates, to ensure that the surfaces really are plane. Here are some ideas that may help you to create correct surface files faster:

- Exploit symmetry: If the room has an axis of symmetry, place the coordinate axis on it. Then use the 'sign'- convention for symmetric /semi symmetric modelling.
- If there are vertical walls and /or features, which repeat vertically (e.g. identical balconies), use the ***CountPt***, ***CountSurf***, ***RevSurf*** statements or indeed ***For..End*** constructs.
- Build the room gradually, testing the .Par file at each stage of growth by loading it into ODEON and have a look at the result.
- Use hybrid statements such as ***Box***, ***Cylinder*** etc.

Where it is difficult to get surfaces to meet properly without either warping or using lots of small surfaces to fill the gaps, allow the surfaces to cut through each other a little. This will usually ensure a watertight result, which is more important, and has only minor drawbacks. These are (i) the apparent surface area will be a little too big, affecting reverberation times estimated using Quick Estimate Reverberation and the room volume estimated by Global Estimate, (ii) crossing surfaces can look odd and hinder clarity in the 3D displays.

Do not try to include small geometrical details at the first attempt. If there are some large surfaces, which are basically plane but contain complex geometrical features (e.g. a coffered ceiling), model them at first as simple planes. Then once the room has been made watertight, make the necessary alterations to the geometry file. The simplified version can also be used in the prediction exercises, to give some idea of the effect of the feature in question.

Examples on parametric modeling

This section will give some short examples on the modelling of rooms using the parametric modelling language of ODEON. The options in this modelling format are many, ranging from typing the model number by number, to dedicated programming. This section will try to give an idea on how to use the language and its keywords. In the default room directory created at the installation of ODEON you may find several other examples in .Par format.

Four ways to model a box

These examples show four ways to model a box-shaped room; using plain numbers, using constants, using constants plus symmetric modelling and using the ***Box*** statement along with the ***MTranslate*** statement. In each example the dimensions of the room are: (W, L, H) = (4, 6, 2.7).

Below the box-shaped room is modelled using plain decimal numbers:

```
Parametric sample BoxFromPureNumbers.par
###
Pt      1       0       2       0
Pt      2       0       -2      0
Pt      3       6       -2      0
Pt      4       6       2       0
:ceiling points
Pt      11      0       2       2.7
Pt      12      0       -2      2.7
Pt      13      6       -2      2.7
Pt      14      6       2       2.7
Surf    1       floor
  1     2       3       4

Surf    2       ceiling
  11    12      13      14
Surf    3       end wall
  1     2       12      11

Surf    4       end wall
  1     2       12      11

Surf    5       side wall
  1     4       14      11

Surf    6       side wall
  2     3       13      12
###
```

Below the box-shaped room is modelled using constants for the definition of W, L and H. Some of the advantages of using parameters in modelling rooms are that it makes it much easier to apply changes to the model (allowing reuse) and often it will also improve the clarity of a model data.

```
Parametric sample BoxFromParameters.par
The box measures are:
Width = 4 metres
Length = 6 metres
Height = 2.7 metres
###
const   W       4
const   L       6
const   H       2.7

Pt      1       0       W/2     0
Pt      2       0       -W/2    0
Pt      3       L       -W/2    0
Pt      4       L       W/2     0

Pt      11      0       W/2     H
Pt      12      0       -W/2    H
Pt      13      L       -W/2    H
Pt      14      L       W/2     H

Surf    1       floor
  1>4

Surf    2       ceiling
  11>14

Surf    3       end wall
  1     2       12      11

Surf    4       end wall
  1     2       12      11
```

```
Surf        5          side wall
  1         4          14         11

Surf        6          side wall
  2         3          13         12
###
```

Below the box-shaped room is modelled using parameters and symmetric modelling syntax (signs on point and surface numbers). The symmetric modelling syntax means less typing and less typing errors:

```
Parametric sample BoxFromParametersUsingSymmetricModelling.par
###
const       W          4
const       L          6
const       H          2.7

Pt          1          0          W/2        0
Pt          2          L          W/2        0

Pt          11         0          W/2        H
Pt          12         L          W/2        H

Surf        1          floor
  1         2          -2         -1

Surf        2          ceiling
  11        12         -12        -11

Surf        3          end wall
  1         11         -11        -1

Surf        4          end wall
  2         12         Mirror     ;Mirror works just as well – defines point -12 and -2
Surf        -5         side wall
  1         2          12         11
###
```

Below the box-shaped room is modelled using the ***Box*** statement, which is the easiest way to create this simple geometry. A ***MTranslate*** statement is used to insert the ***Box*** at the same position as in the three other examples:

```
Parametric sample BoxStatement.Par
###
const L 6
const W 4
const H 2.7

MTranslate l/2 0 0

Box 1 l w h tb Walls and floor
###
```

Modeling a cylinder

This example shows two different ways to create a cylindrical room with a floor and a ceiling. In the first example the room is modelled using the Cylinder statement:

```
Parametric Sample CylinderStatement.Par
###
const N 16
const R 15
const H 10
```

```
Cylinder 1000        N        R        360      H        TB Cylindrical room
###
```

The ***Cylinder*** statement is of course the easiest way to model a cylinder, however sometimes more flexibility is needed (e.g. different radius in top and bottom). In the second example the corners in the room are modelled using the ***CountPt*** statement and the cylindrical surfaces are modelled using the ***RevSurf*** statement. Notice that the number of points created by the ***CountPt*** statement is one higher than the number of sections in the ***RevSurf*** statement. The bottom and top of the room is modelled using the ***Surf*** statement, notice that points used by these surfaces are referenced using the statement ***100>100+N-1*** rather than writing each of the sequential points. This is not only a faster way to write things, it also allows a rapid change to the number of sections in the cylinder by simply changing the ***N*** constant.

```
Parametric sample, a cylinder RevSurfCylinder.Par
###
const N      16
const R      15
const H      10

CountPt     100 N+1 R*CosD((PtCounter)*360/N)  R*SinD((PtCounter)*360/N) 0
CountPt     200 N+1 R*CosD((PtCounter)*360/N)  R*SinD((PtCounter)*360/N) H

RevSurf 300 100 200 Sections  cylinder walls

Surf         100        Circular floor
  100>100+N-1

Surf         2 Circular ceiling
  200>200+N-1
###
```

Modelling a box-shaped room with columns in two dimensions, using two level For..End constructs

When modelling geometries that have more than one level of symmetry, it is advantageous to use ***For..End*** constructs. This example shows how to model columns in two dimensions in a room using a two-level ***For..End*** construct.

Each column is created using 8 points and 4 surfaces, thus the numbering used by points and surfaces is incremented by 8 each time a column is created. This is done by incrementing the predefined variable ***NumbOffSet*** by eight for each column in order to make surface and point numbers unique. The different positions of the points used for each column are obtained, using ***MTranslate*** and ***MReset.***

```
Parametric sample BoxColumnRoom.Par
###
 const L 10
 const W 4
 const H 3
 const NumColX 4
 const NumColY 3
 const ColumnW 0.3

MTranslate l/2 0 0
Box 1 l w h tb walls in the room
:modelling the columns

for ColYCnt 1 NumColY
MReset
   MTranslate L/(NumColX+1) w/2-ColYCnt*W/(NumColY+1) 0
   for ColXCnt 1 NumColX
            NumbOffSet NumbOffSet+8   ;comment: hint! setting NumbOffSet to Auto would do the same
job
```

```
        Box 1 ColumnW ColumnW h n columns in the room
        MTranslate L/(NumColX+1) 0 0
    end
end
###
```

Using hybrid statements and coordinate manipulation

The following example demonstrates an example on how to use the hybrid statements ***Cylinder2*** and ***Dome2*** as well as the coordinate manipulations, which are essential for the use of the hybrid statements.

This example is a rather complex one, so the main parts of the file is explained below:

Line 3-7	Defining constants.
Line 8-9	Inserting the cylindrical wall, which needs a rotation of 90° around the Z-axis.
Line 11	The foot-points of the cylindrical wall, which are temporarily stored in ***PListA***, are stored in ***PList0*** for later use (definition of the floor).
Line 12-13	Inserting the dome shaped ceiling. The Z-rotation has already been set to 90° when the wall was created.
Line 14-18	Setting the coordinate manipulation for the ceiling and creating the ceiling.
Line 19	Resetting the coordinate manipulation to work in absolute coordinates
Line 20-23	Creating wall/floor points
Line 24-25	Defining floor, using the 'cylinder points' stored in ***Plist0***.
Line 28-29	Defining side walls using symmetric modelling.
Line 30-31	Defining back wall, using the 'ceiling cylinder points' which is still stored in ***PListB***.

```
1.  Dome2 and cylinder2 x 2 room.par
2.  ###
3.  Const H 5
4.  Const L 10
5.  Const W 15
6.  Const N 12
7.  Const HCurve 4

8.  MRotateZ 90
9.  Cylinder 1000 N W/2 180 H N
10. //Stores PListA for later use with floor
11. PList0 PListA

12. MTranslate 0 0 H
13. Dome2 2000 N W HCurve 180 Halfdome

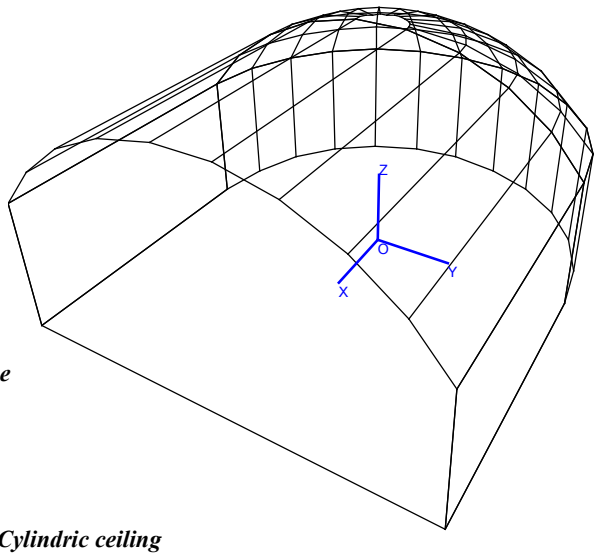
14. MReset
15. MRotateZ 90
16. MRotateY 90
17. MTranslate 0 0 H
18. Cylinder2 3000 ONVert W HCurve L n Cylindric ceiling

19. MReset
20. Pt 1 0 W/2 0
21. Pt 2  L W/2 0
22. Pt 3 0 W/2 H
23. Pt 4  L W/2 H

24. Surf 1 Floor
25. 2 PList0 -2

26. //when done using PList0, it's a good habit to Reset it
27. ResetPList0

28. Surf -2 Side Walls
```

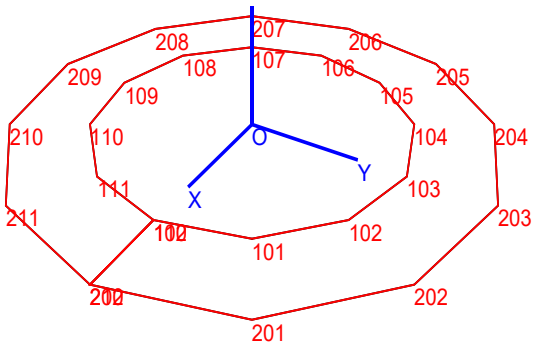


```
29.  1 2 4 3
30.  Surf 3 BackWall
          2     PListB -2
31.  ###
```

Defining surfaces with concave edges

Most surfaces in the geometries used with ODEON will probably have convex edges (rectangles, cylindrical surfaces etc.), however in ODEON, it is possible to define surfaces with cavities, even surfaces with holes. Such surfaces are defined just like any other surface, by creating a list of corners where the listing is obtained by travelling around the surface's edge (in either direction). Below are two examples; one with a donut-shaped balcony floor and another with a cylindrical window opening in a ceiling.

In the donut example two 'rings of corners' are created using the ***CountPt*** statement, notice that the point 100 is equal to point 112 and point 200 is equal to point 212. The donut surface is created, simply by connecting the inner and outer ring of points into one surface. It doesn't matter whether one of the rings are created clock or counter-clockwise. The surface is created from the following list of points: ***100,101,102,…,110,111,112,200,201,202,…..,210,211,212.***




```
DonutSurface.par
###
Const R1 10
Const R2 15
Const N 12
CountPt     100 N+1          R1*CosD(360*PtCounter/N)          R1*SinD(360*PtCounter/N) 0
CountPt 200 N+1               R2*CosD(360*PtCounter/N)          R2*SinD(360*PtCounter/N) 0

Surf 100 Donut surface
 100>100+N 200>200+N
###
```

The window example shows how a cylindrical window opening is created in ceiling surface. The interesting surface in this example is surface 1, the ceiling surface. The surface is created from the following list of points:1,100,101,102,103….,111,112,1,2,3,4.

CeilingWithWindowTube.par
###
Const R1 0.75
Const R2 0.5
Const N 12

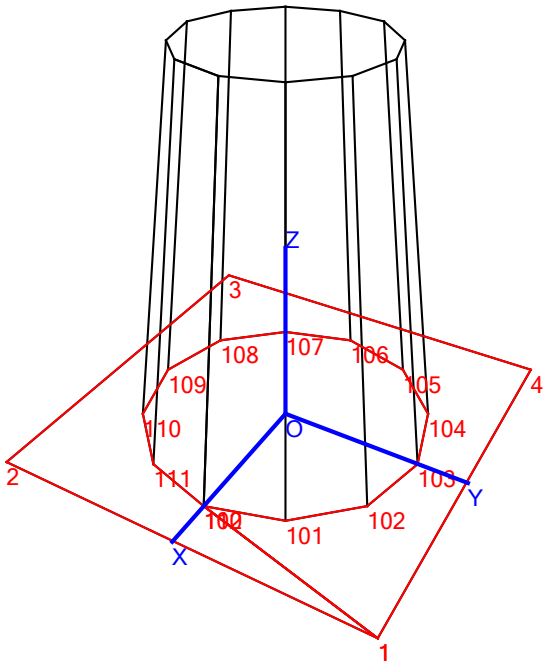
Pt 1 1 1 0
Pt 2 1 -1 0
Pt 3 -1 -1 0
Pt 4 -1 1 0

*CountPt 100 N+1 R1*CosD(360*PtCounter/N)*
*R1*SinD(360*PtCounter/N) 0*
*CountPt 200 N+1 R2*CosD(360*PtCounter/N)*
*R2*SinD(360*PtCounter/N) 2*

Surf 1 Ceiling
1 100>100+N 1>4

RevSurf 2 100 200 N Window tube

Surf 100 Window /glass
200>200+N-1



###

Appendix I: Importing DXF/DWG files with BIM information (Revit)

An alternative way to transfer BIM information from a Revit model to ODEON is to use the DXF or the DWG format. When a DXF/DWG file is imported, ODEON checks if the file has relevant BIM information. If this is the case, the BIM information is used to produce an optimised geometrical model, following the same processing as for the IFC format (see Section 0). Otherwise, the file is processed as a regular geometry (see Section 2.6).

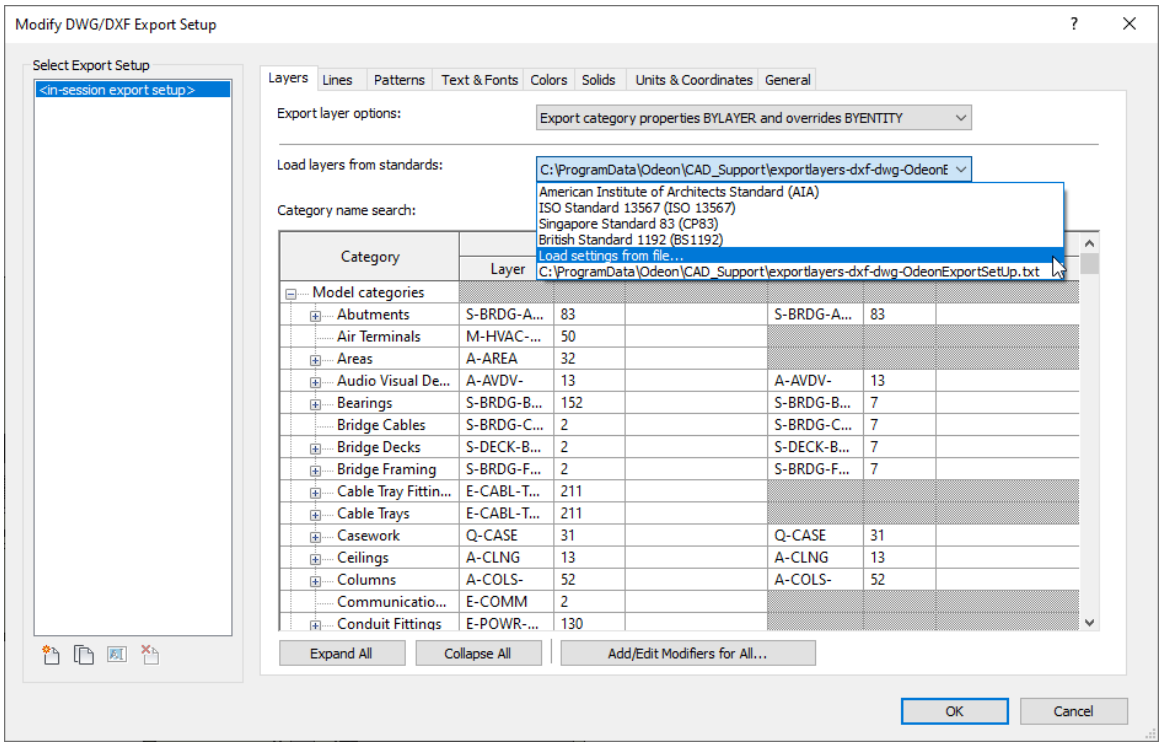
Important: the DXF and DWG files should be created with Revit to allow BIM processing by ODEON.

Note: Compared to IFC files, the reading of DXF/DWG files is slower. For this reason, we generally recommend the IFC format rather than DXF/DWG to get Revit models into ODEON.

ODEON Export layer file

The different categories and subcategories of Revit are mapped to ODEON layers in the DXF/DWG file by loading the Odeon export setup file exportLayers-dxf-dwg-Odeon.txt, located in: C:\ProgramData\Odeon\CAD_Support.

Go to File/Export/Options/Export setups DWG/DXF. In the Load layers from standards dropdown menu, click on Load settings from file and search for the export file.



Note that the allowed categories and subcategories for exporting can be modified by the user. In the text file, the last column indicates whether to accept (Y) or reject (N) each element for further processing.

The difference with the IFC export is that the mapping is done directly between Revit categories and ODEON layers. This procedure does not prevent disallowed categories to enter the DXF/DWG file, they will just not be processed further in the import to ODEON. The proposed mapping is very restrictive, meaning that the majority of the Revit categories and subcategories will not be included in the ODEON model, as they are irrelevant for acoustic modelling.

Prepare your 3D View before exporting

The next step is to clean the 3D View, which is accessed in the View tab of Revit. Invisible geometry in the exported 3D View will not be written to the DXF/DWG file. It is thus very convenient to hide every element that is not relevant for the room acoustic simulation, as described for IFC export in Section 0. It is also preferable to hide the elements belonging to the disallowed Revit categories and subcategories.

This will make your DXF/DWG files lighter for ODEON import. Actually, the reading of the file is the most expensive part of the import procedure. It could take up to several minutes if the file is large.

As discussed for IFC import, you should use the coarser level of detail representation for the elements in the model.

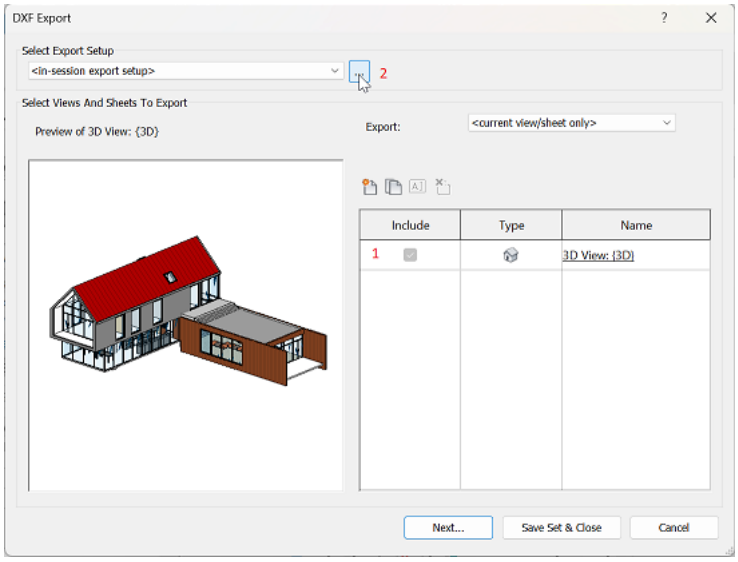
Export setup step by step

After your 3D View is prepared for the export, you can proceed to File/Export/CAD Formats and select either the DXF or the DWG format.

Both exports have the same settings. In the DXF or DWG export window two actions are required:
1. Make sure to select your current 3DView for the export.
2. Modify the export setup by clicking the three dots in the Select export setup section.

In the DXF/DWG export setup window, pay attention to the following options:

- **Layers tab:** make sure the ODEON setup file is selected.
- **Solids tab:** we recommend the use of ACIS solids.
- **Units & Coordinates tab:** make sure that **Internal Origin** is selected as Coordinate Base.



The resulting DXF/DWG file can be imported in Odeon (just drag and drop the file in the Odeon canvas). The import procedure inside Odeon is similar to the import of IFC files, as it allows processing of BIM elements. The same guidelines can thus be followed (see Section 0).

Appendix J: Mathematical Expressions

In this section, mathematical expressions used in the .Par modelling format and in the Room acoustic parameter list are presented. Constants, variables, point numbers, surface numbers and coordinates may be defined using mathematical expressions. Where integer numbers are expected (Counter ranges in for…end loops, point, surface numbers, etc.), the results of mathematical expressions are automatically rounded to the nearest whole number.

Operation	Syntax	Example
Addition	+	2+5 = 7
Subtraction	-	3-1 = 2
Multiplication	*	2*3 = 6
Division	/	4/2 = 2
Power	Base^ Exponent or Power(Exponent,Base)	2^3 = 8 or Power(3,2) = 8
Root	Root(Index,Radicand)	Root(3,8) = 2
Round	Round(X)	Round(2.67676) = 3
Truncation	Trunc(X) or Int(X)	Trunc(1.7) = 1
Sine of an angle in radians	Sin(X)	Sin(0) = 0
Cosine of an angle in radians	Cos(radians)	Cos(PI/4)= 0,707106781186547573
Tangent of an angle in radians	Tan(radians)	Tan(PI/4) = 1
Cotangent of an angle in radians	Cotan(radians)	Cotan(180) = 0
Hyperbolic Sine of an angle in radians	Sinh(radians)	Sinh(0) = 0
Hyperbolic Cosine of an angle in radians	Cosh(radians)	Cosh(0) = 1
Sine of an angle in degrees	SinD(radians)	SinD(90) = 1
Cosine of an angle in degrees	CosD(degrees)	CosD(0) = 1
Tangent of an angle in degrees	TanD(degrees)	TanD(45) = 1
Cotangent of an angle in degrees	CotanD(degrees)	CotanD(90) = 0
Inverse Sine in radians	ArcSin(Y)	ArcSin(-Sqrt(2)/2)*180/PI = -45
Inverse Cosine in radians	ArcCos(X)	ArcCos(Sqrt(2)/2)*180/PI = 45
Inverse Tangent in radians	ArcTan(Y)	ArcTan(1)*180/PI= 45
Inverse Tangent II in radians	ArcTan2(X,Y)	ArcTan2D(1,-1)*180/PI = - 45
Inverse Sine in degrees	ArcSinD(Y)	ArcSin(-Sqrt(2)/2)*180/PI = -45
Inverse Cosine in degrees	ArcCosD(X)	ArcCos(Sqrt(2)/2)*180/PI = 45
Inverse Tangent in degrees	ArcTanD(Y)	ArcTan(1) = 45
Inverse Tangent II in degrees	ArcTan2D(X,Y)	ArcTan2D(1,-1) = - 45
Exponential	Exp(X)	Exp(1)= 2.71828182845904509
Natural Logarithm	Ln(X)	Ln(2.718281828459045091) = 1
Logarithm base 10	Log10(X)	Log10(100) = 2
Logarithm base 2	Log2(X)	Log2(8) = 3
Square	Sqr(X)	Sqr(2) = 4
Square root	Sqrt(X)	Sqrt(2)= 1.41421356237309515
Radius	Radius(A,B)	Radius(3,4) = 5
Absolute value	Abs(X)	Abs(-2342) = 2342
Sign	Sign(X)	Sign(-2) = -1; Sign(0) = 0; Sign(3) = 1
Minimum of two numbers	Min(X,Y)	Min(23,12) = 12
Maximum of two numbers	Max(X,Y)	Max(23,22) = 23