



Model created in COMSOL Multiphysics 6.4

Chamber Music Hall

Introduction

The main purpose of performance spaces such as concert halls is to deliver sound of high quality to the audience; acoustic conditions are therefore of utmost importance. These conditions can be investigated numerically to predict the behavior of the room before the building or renovation phase is started. In spaces with large dimensions compared to the wavelengths of interest, like the one at hand, acoustic ray tracing is the best fitted solution for numerical simulations.

This model studies the acoustics of the Small Hall in the Konzerthaus Berlin. It is a moderately sized hall with 386 seats, primarily used for chamber music concerts. The model is set up with the *Ray Acoustics* physics interface. The room acoustic parameters are derived from impulse responses with 10 pairs of source-receiver positions, and the results are compared to in-situ measurements (see [Ref. 1](#)). The goal of this study is to assess the accuracy of the calculations; for a detailed guide on how to set up a room acoustic simulation see the [Small Concert Hall Acoustics](#) model, also included in the Acoustics Module Application Library.

Note: The geometry model, room data, and measurement data used here were provided by the authors of [Ref. 1](#) and [Ref. 2](#) under the [Creative Commons BY-SA 4.0](#) license; the public database can be found in [Ref. 2](#). One modification has been made to the geometry model: the seating on the central area and on the balconies has been extruded to a height of 0.8 m instead of being represented as flat surfaces.

Model Definition

The model represents a concert hall with a volume $V = 2350 \text{ m}^3$, excluding the coupled attic volume. The geometry was provided by [Ref. 2](#), as well as the assignment of materials to the different surfaces, absorption and scattering data, source and receiver positions, and measurement data. The only modification that has been made to the provided material is the geometry of the seating area. In the original model, the central seats on the ground floor and the seats on the balcony are represented as flat surfaces, whereas in this study they have been extruded to a height of 0.8 m. The inside of the hall geometry can be seen in [Figure 1](#).

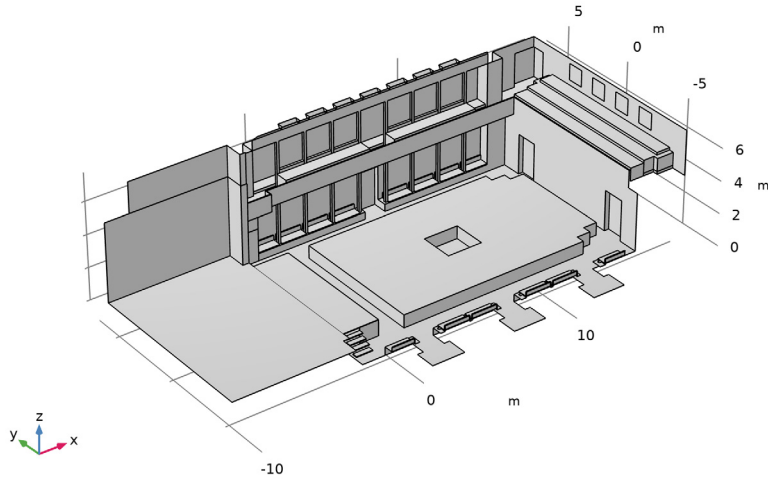


Figure 1: Interior geometry of the chamber music hall.

The simulation is performed in 1/3-octave bands ranging from 100 Hz to 5000 Hz. Two omnidirectional source positions are defined on the stage, together with five receiver positions spread over the central seating area. Their coordinates are given in Table 1, with the location of the origin centered at the foot of the stage.

TABLE 1: SOURCE AND RECEIVER POSITIONS.

POINT	X-COORDINATE	Y-COORDINATE	Z-COORDINATE
Source 1	-2.02 m	2 m	2.38 m
Source 2	-3.32 m	-2 m	2.38 m
Receiver 1	7.84 m	0 m	1.23 m
Receiver 2	2.165 m	3.441 m	1.23 m
Receiver 3	9.227 m	2.366 m	1.23 m
Receiver 4	5.86 m	-2.359 m	1.23 m
Receiver 5	12.726 m	-3.24 m	1.23 m

The size of the receivers is set to match the width of one seat, with a receiver radius $r = 0.3$ m. The number of rays emitted by each source is then determined to limit the error

in the calculated impulse responses. For an expected error of 1 dB in every time interval Δt of the response, the number of rays should be (see Ref. 3)

$$N_{\text{rays}} = 4.34^2 \frac{V}{\pi r^2 c \Delta t} \quad (1)$$

With $\Delta t = 0.01$ s, the resulting value is rounded up to $N_{\text{rays}} = 46,000$. Boundary conditions are defined as absorption and scattering coefficients in 1/3-octave bands. The amplitude attenuation of air was computed at the 1/3-octave band center frequencies from a *Pressure Acoustics* model and is imported from the file `chamber_music_hall_air_attenuation.txt`.

Results and Discussion

The power carried by each ray emitted from source 1 at 5000 Hz is shown in [Figure 2](#) at different times. In this model the intensity along each ray is not computed in order to limit the number of degrees of freedom solved for in the simulation, hence reducing the computation time and the size of the saved file. As a result, it is not possible to plot local wavefront variables that depend on curvature computation, such as the sound pressure level. Nevertheless, the acoustic power and the reflection count along each ray are sufficient to generate the room impulse responses.

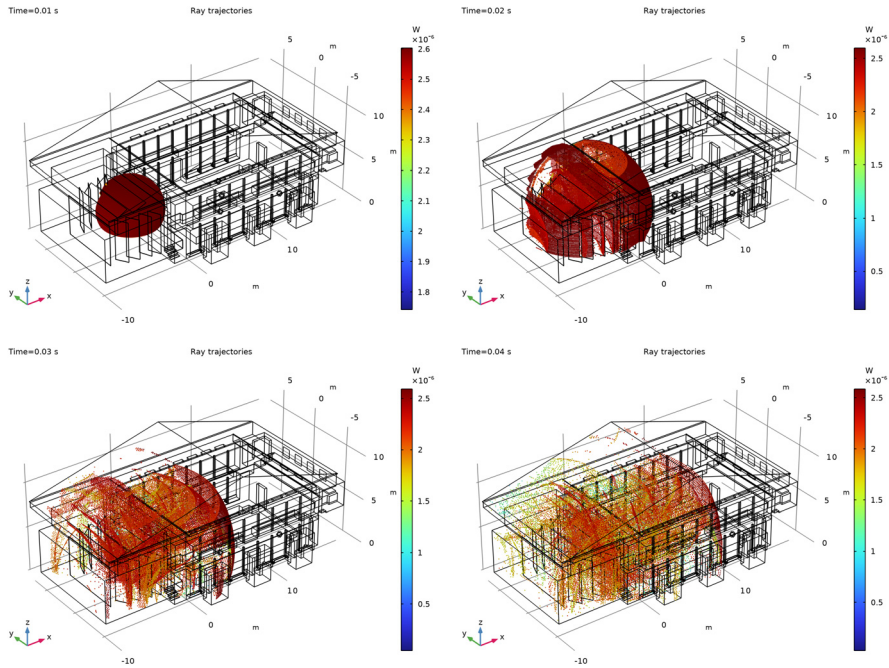


Figure 2: Ray location and power from source 1 at 5000 Hz after 10 ms (top left), 20 ms (top right), 30 ms (bottom left), and 40 ms (bottom right).

The impulse response energy decay used to compute the room acoustic parameters for one source-receiver pair is found in [Figure 3](#). The curves are seen to be smooth from 0 dB to at least -40 dB, and the response duration is long enough to allow the necessary decay for reverberation time calculation. The results obtained should therefore be reliable.

Similarly to measurement procedures, level decay curves are generated for all the source-receiver pairs in the model. Hence, 10 values are derived for each room acoustic parameter. The average over the 10 source-receiver pairs is then calculated to obtain an overall value for the room.

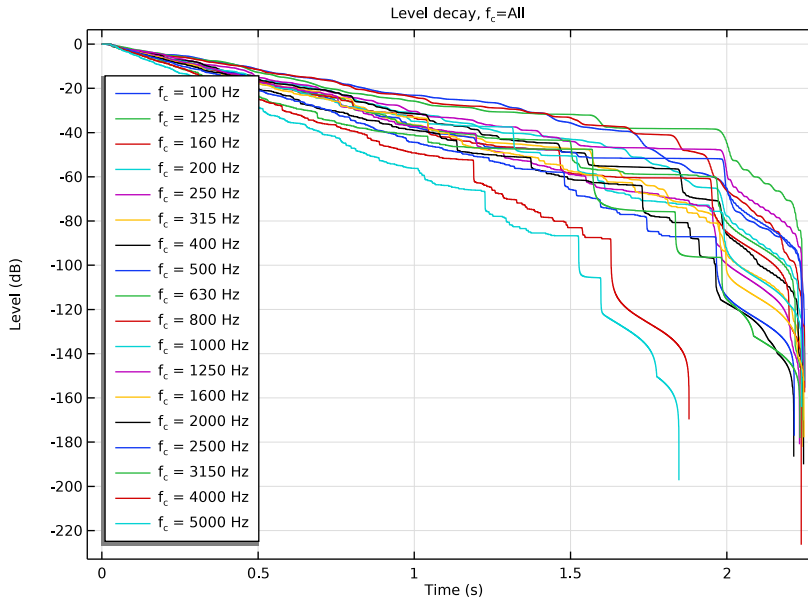


Figure 3: Level decay curves for source 1 and receiver 1.

The comparison between the measured and calculated Early Decay Time (EDT) is plotted in Figure 4. The interval representing three times the just noticeable difference (JND) is also depicted. A satisfying match is observed, with the result of the calculation lying within 3 JND of the measurement in many 1/3-octave bands or slightly above this interval otherwise.

The measured and calculated reverberation times T20 are also compared in Figure 5. In this case, the reverberation time is overestimated by the calculation. This finding concurs with Ref. 1, where T20 was overestimated by all the simulation algorithms. Since this issue did not arise in the EDT, the difference between measurement and calculation does not originate from the early part of the sound field.

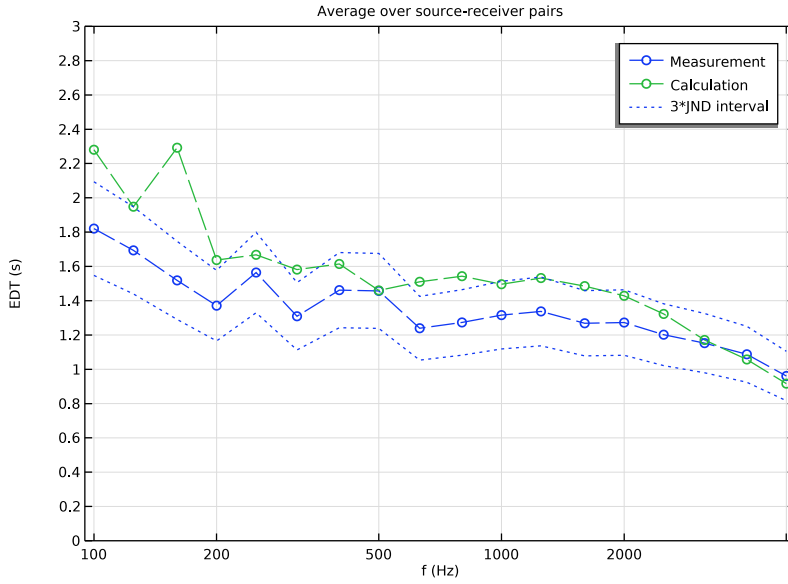


Figure 4: Early Decay Time averaged across the room.

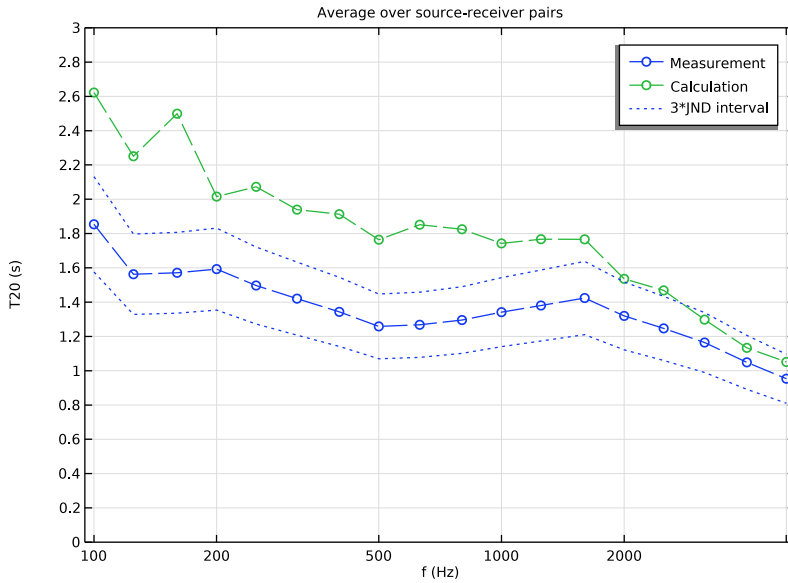


Figure 5: Reverberation time T20 averaged across the room.

Two more acoustics parameters, the clarity C80 and the definition D, are shown in [Figure 6](#) and [Figure 7](#) respectively. They both fit nicely with the measurements and appear well within the 3 JND interval over the whole frequency range.

In the subjective perception of room acoustics, early reflections that reach listeners before 50 ms to 100 ms are considered to contribute positively by reinforcing the direct sound (see [Ref. 4](#)). C80 and D both give an indication of this aspect with their energy ratios of early sound field to either late or total sound field. The difference in their definitions of the transition between early and late reflections stems from their respective purposes, with C80 describing the transparency of music and D the speech intelligibility. Moreover, EDT only takes into account the first 10 dB of the level decay to focus on the early energy. As a result, it is more closely related to the perceived reverberance of a room than other quantifications of reverberation time. Finding a good fit with the measurements in these three parameters is therefore an encouraging sign for the accuracy of the simulation.

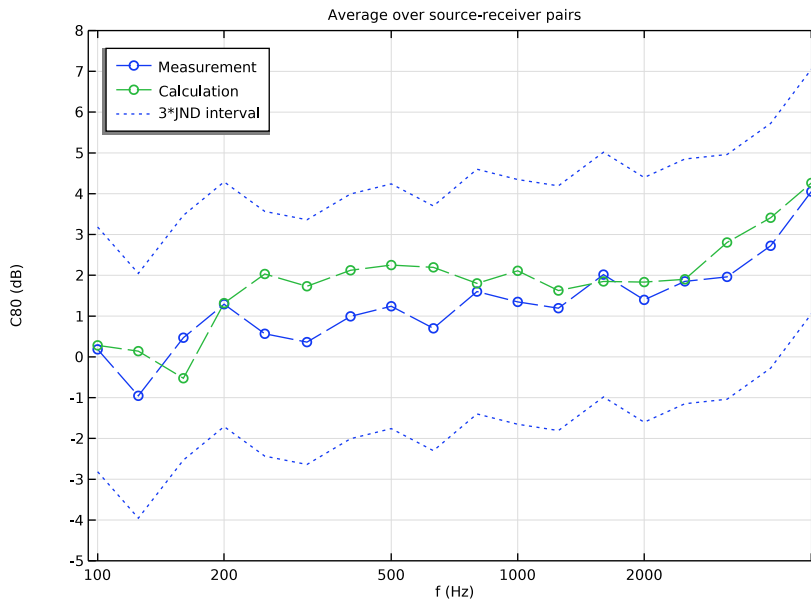


Figure 6: Clarity C80 averaged across the room.

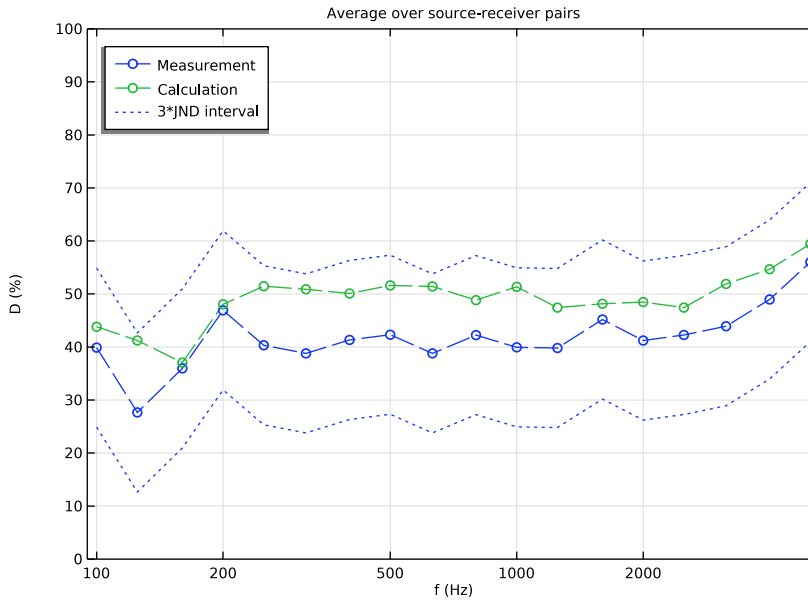


Figure 7: Definition D averaged across the room.

Overall, a good accuracy has been found in the study of this chamber music hall. The calculation results matched closely with in-situ measurements for most of the common room acoustic parameters. This demonstrates the potential for modeling advanced room acoustic cases.

Notes About the COMSOL Implementation

The rays that are emitted in the simulation need to be terminated when their energy content becomes too small to avoid unnecessary calculations. This can be done by defining a power threshold as termination criterion. With the total source power P_0 , each ray is emitted with an initial power P_0/N_{rays} . In this model, a ray is terminated when the power it carries is 10^7 times smaller than initially, in other words when its power has dropped by 70 dB. The power threshold for termination is then expressed as $P_0/N_{\text{rays}} \cdot 10^{-7}$.

When plotting an energy decay curve, the EDT and reverberation times are automatically checked to detect potentially large differences. These can be due to a small number of rays or an early termination of the rays and simulation. In this model, a warning might appear

depending on the random effects of scattering; however, the comparison with measurement data shows that the simulation is well set.

Some postprocessing is needed in this model in order to obtain results averaged over the room. After calculating the impulse responses, the acoustic parameters for the different source-receiver pairs must be interpolated as functions of frequency. First, an **Interpolation** is created for each impulse response under **Global Definitions**. A new **Study** is then added with the same **Parametric Sweep** as the previous ones but no ray tracing step. The role of this study is to load the newly created interpolation functions without running a full calculation of the model again, its output results are therefore not relevant. Once the new study has been computed, the acoustic parameters can be processed to return values averaged over the room.

Given the number of impulse responses and the time needed to render them, it is advisable to save the plot data in the model. However, this can create a very large saved file. To reduce the file size by up to a factor 10, the **Only store receiver data and accumulated variables** option is activated. This allows to get rid of all ray information that does not contribute to any of the receivers in the model. However, this prevents from studying results that are not linked to the **Receiver** feature, such as the **Ray Trajectories** plot for example. Therefore, a first *Ray Acoustics* physics interface with full solution data is set up in the model and solved for a single frequency. The second Ray Acoustics interface then only contains the receiver data needed to calculate the impulse responses and their associated room acoustic parameters. Some further disc space can be spared by setting **File > Preferences > Save > Optimize for > File size**.

References

1. F. Brinkmann, L. Aspöck, D. Ackermann, S. Lepa, M. Vorländer, and S. Weinzierl, “A round robin on room acoustical simulation and auralization,” *J. Acoust. Soc. Am.*, vol. 145, pp. 2746–2760, 2019, doi: [10.1121/1.5096178](https://doi.org/10.1121/1.5096178).
2. L. Aspöck, F. Brinkmann, D. Ackermann, S. Weinzierl, and M. Vorländer, “BRAS - Benchmark for Room Acoustical Simulation,” 2020, publications.rwth-aachen.de/record/808874.
3. M. Vorländer, *Auralization: Fundamentals of Acoustics, Modelling, Simulation, Algorithms and Acoustic Virtual Reality*, Springer, 2008.
4. H. Kuttruff, *Room Acoustics*, CRC Press, 2009.


Application Library path: Acoustics_Module/Building_and_Room_Acoustics/
chamber_music_hall

Modeling Instructions




This section contains the modeling instructions for the Chamber Music Hall model. They are followed by the [Geometry Modeling Instructions](#) section.

From the **File** menu, choose **New**.

NEW

In the **New** window, click  **Model Wizard**.


MODEL WIZARD

- 1 In the **Model Wizard** window, click  **3D**.
- 2 In the **Select Physics** tree, select **Acoustics > Geometrical Acoustics > Ray Acoustics (rac)**.
- 3 Click **Add**.
- 4 Click  **Study**.
- 5 In the **Select Study** tree, select **Preset Studies for Selected Physics Interfaces > Ray Tracing**.
- 6 Click  **Done**.

Start by loading parameter definitions, material properties, and measurement data.


GLOBAL DEFINITIONS

Parameters 1 - Study setup




- 1 In the **Model Builder** window, under **Global Definitions** click **Parameters 1**.
- 2 In the **Settings** window for **Parameters**, type Parameters 1 - Study setup in the **Label** text field.
- 3 Locate the **Parameters** section. Click  **Load from File**.
- 4 Browse to the model's Application Libraries folder and double-click the file chamber_music_hall_parameters1.txt.

Parameters 2 - Source and receiver positions

- 1 In the **Home** toolbar, click  **Parameters** and choose **Add > Parameters**.

- 2 In the **Settings** window for **Parameters**, type Parameters 2 - Source and receiver positions in the **Label** text field.
- 3 Locate the **Parameters** section. Click  **Load from File**.
- 4 Browse to the model's Application Libraries folder and double-click the file chamber_music_hall_parameters2.txt.
Create interpolation functions to import the air attenuation, the absorption and scattering coefficients of the different surfaces, and the acoustic parameters measured in the room.

Interpolation 1 (int1)



- 1 In the **Home** toolbar, click  **Functions** and choose **Global > Interpolation**.
- 2 In the **Settings** window for **Interpolation**, locate the **Definition** section.
- 3 From the **Data source** list, choose **File**.
- 4 Click  **Browse**.
- 5 Browse to the model's Application Libraries folder and double-click the file chamber_music_hall_air_attenuation.txt.
- 6 Click  **Import**.
- 7 In the **Function name** text field, type a_air.
- 8 Locate the **Interpolation and Extrapolation** section. From the **Interpolation** list, choose **Nearest neighbor**.
- 9 Locate the **Units** section. In the **Function** table, enter the following settings:

Function	Unit
a_air	Np/m

- 10 In the **Argument** table, enter the following settings:


Argument	Unit
Column 1	Hz

Interpolation 2 (int2)



- 1 In the **Home** toolbar, click  **Functions** and choose **Global > Interpolation**.
- 2 In the **Settings** window for **Interpolation**, locate the **Definition** section.
- 3 From the **Data source** list, choose **File**.
- 4 Click  **Browse**.

- 5 Browse to the model's Application Libraries folder and double-click the file `chamber_music_hall_ceiling.csv`.
- 6 Locate the **Data Column Settings** section. In the table, click to select the cell at row number 1 and column number 1.
- 7 In the **Unit** text field, type Hz.
- 8 In the table, enter the following settings:

Columns	Type	Settings
Column 2	Function values	Function name=a_ceiling


- 9 In the **Name** text field, type `a_ceiling`.
- 10 In the **Unit** text field, type 1.
- 11 In the table, click to select the cell at row number 3 and column number 1.
- 12 In the **Name** text field, type `s_ceiling`.
- 13 In the **Unit** text field, type 1.
- 14 Locate the **Interpolation and Extrapolation** section. From the **Interpolation** list, choose **Nearest neighbor**.
- 15 Locate the **Definition** section. Click  **Import**.

Interpolation 3 (int3)



- 1 In the **Home** toolbar, click  **Functions** and choose **Global > Interpolation**.
- 2 In the **Settings** window for **Interpolation**, locate the **Definition** section.
- 3 From the **Data source** list, choose **File**.
- 4 Click  **Browse**.
- 5 Browse to the model's Application Libraries folder and double-click the file `chamber_music_hall_floor.csv`.
- 6 Locate the **Data Column Settings** section. In the table, click to select the cell at row number 1 and column number 1.
- 7 In the **Unit** text field, type Hz.
- 8 In the table, enter the following settings:

Columns	Type	Settings
Column 2	Function values	Function name=a_floor


- 9 In the **Name** text field, type `a_floor`.
- 10 In the **Unit** text field, type 1.

- 11 In the table, click to select the cell at row number 3 and column number 1.
- 12 In the **Name** text field, type s_floor.
- 13 In the **Unit** text field, type 1.
- 14 Locate the **Interpolation and Extrapolation** section. From the **Interpolation** list, choose **Nearest neighbor**.
- 15 Locate the **Definition** section. Click  **Import**.


Interpolation 4 (int4)


- 1 In the **Home** toolbar, click  **Functions** and choose **Global > Interpolation**.
- 2 In the **Settings** window for **Interpolation**, locate the **Definition** section.
- 3 From the **Data source** list, choose **File**.
- 4 Click  **Browse**.
- 5 Browse to the model's Application Libraries folder and double-click the file chamber_music_hall_plaster.csv.
- 6 Locate the **Data Column Settings** section. In the table, click to select the cell at row number 1 and column number 1.
- 7 In the **Unit** text field, type Hz.
- 8 In the table, enter the following settings:

Columns	Type	Settings
Column 2	Function values	Function name=a_plaster


- 9 In the **Name** text field, type a_plaster.
- 10 In the **Unit** text field, type 1.
- 11 In the table, click to select the cell at row number 3 and column number 1.
- 12 In the **Name** text field, type s_plaster.
- 13 In the **Unit** text field, type 1.
- 14 Locate the **Interpolation and Extrapolation** section. From the **Interpolation** list, choose **Nearest neighbor**.
- 15 Locate the **Definition** section. Click  **Import**.

Interpolation 5 (int5)



- 1 In the **Home** toolbar, click  **Functions** and choose **Global > Interpolation**.
- 2 In the **Settings** window for **Interpolation**, locate the **Definition** section.
- 3 From the **Data source** list, choose **File**.

- 4 Click  **Browse**.
- 5 Browse to the model's Application Libraries folder and double-click the file `chamber_music_hall_seating.csv`.
- 6 Locate the **Data Column Settings** section. In the table, click to select the cell at row number 1 and column number 1.
- 7 In the **Unit** text field, type Hz.
- 8 In the table, enter the following settings:

Columns	Type	Settings
Column 2	Function values	Function name=a_seating


- 9 In the **Name** text field, type `a_seating`.
- 10 In the **Unit** text field, type 1.
- 11 In the table, click to select the cell at row number 3 and column number 1.
- 12 In the **Name** text field, type `s_seating`.
- 13 In the **Unit** text field, type 1.
- 14 Locate the **Interpolation and Extrapolation** section. From the **Interpolation** list, choose **Nearest neighbor**.
- 15 Locate the **Definition** section. Click  **Import**.

Interpolation 6 (int6)



- 1 In the **Home** toolbar, click  **Functions** and choose **Global > Interpolation**.
- 2 In the **Settings** window for **Interpolation**, locate the **Definition** section.
- 3 From the **Data source** list, choose **File**.
- 4 Click  **Browse**.
- 5 Browse to the model's Application Libraries folder and double-click the file `chamber_music_hall_stagepanels.csv`.
- 6 Locate the **Data Column Settings** section. In the table, click to select the cell at row number 1 and column number 1.
- 7 In the **Unit** text field, type Hz.
- 8 In the table, enter the following settings:

Columns	Type	Settings
Column 2	Function values	Function name=a_stagepanels


- 9 In the **Name** text field, type `a_stagepanels`.

- 10 In the **Unit** text field, type 1.
- 11 In the table, click to select the cell at row number 3 and column number 1.
- 12 In the **Name** text field, type s_stagepanels.
- 13 In the **Unit** text field, type 1.
- 14 Locate the **Interpolation and Extrapolation** section. From the **Interpolation** list, choose **Nearest neighbor**.
- 15 Locate the **Definition** section. Click  **Import**.


Interpolation 7 (int7)


- 1 In the **Home** toolbar, click  **Functions** and choose **Global > Interpolation**.
- 2 In the **Settings** window for **Interpolation**, locate the **Definition** section.
- 3 From the **Data source** list, choose **File**.
- 4 Click  **Browse**.
- 5 Browse to the model's Application Libraries folder and double-click the file chamber_music_hall_structuredplaster.csv.
- 6 Locate the **Data Column Settings** section. In the table, click to select the cell at row number 1 and column number 1.
- 7 In the **Unit** text field, type Hz.
- 8 In the table, enter the following settings:

Columns	Type	Settings
Column 2	Function values	Function name=a_structuredplaster


- 9 In the **Name** text field, type a_structuredplaster.
- 10 In the **Unit** text field, type 1.
- 11 In the table, click to select the cell at row number 3 and column number 1.
- 12 In the **Name** text field, type s_structuredplaster.
- 13 In the **Unit** text field, type 1.
- 14 Locate the **Interpolation and Extrapolation** section. From the **Interpolation** list, choose **Nearest neighbor**.
- 15 Locate the **Definition** section. Click  **Import**.

Interpolation 8 (int8)




- 1 In the **Home** toolbar, click  **Functions** and choose **Global > Interpolation**.
- 2 In the **Settings** window for **Interpolation**, locate the **Definition** section.

- 3 From the **Data source** list, choose **File**.
- 4 Click  **Browse**.
- 5 Browse to the model's Application Libraries folder and double-click the file `chamber_music_hall_windows.csv`.
- 6 Locate the **Data Column Settings** section. In the table, click to select the cell at row number 1 and column number 1.
- 7 In the **Unit** text field, type Hz.
- 8 In the table, enter the following settings:

Columns	Type	Settings
Column 2	Function values	Function name=a_windows

- 9 In the **Name** text field, type `a_windows`.
- 10 In the **Unit** text field, type 1.
- 11 In the table, click to select the cell at row number 3 and column number 1.
- 12 In the **Name** text field, type `s_windows`.
- 13 In the **Unit** text field, type 1.
- 14 Locate the **Interpolation and Extrapolation** section. From the **Interpolation** list, choose **Nearest neighbor**.
- 15 Locate the **Definition** section. Click  **Import**.

Interpolation 9 (int9)

- 1 In the **Home** toolbar, click  **Functions** and choose **Global > Interpolation**.
- 2 In the **Settings** window for **Interpolation**, locate the **Definition** section.
- 3 From the **Data source** list, choose **File**.
- 4 Click  **Browse**.
- 5 Browse to the model's Application Libraries folder and double-click the file `chamber_music_hall_EDT.txt`.
- 6 Click  **Import**.
- 7 In the **Function name** text field, type `EDT_meas`.
- 8 Locate the **Interpolation and Extrapolation** section. From the **Interpolation** list, choose **Nearest neighbor**.

9 Locate the **Units** section. In the **Function** table, enter the following settings:

Function	Unit
EDT_meas	s

10 In the **Argument** table, enter the following settings:

Argument	Unit
Column I	Hz

Interpolation 10 (int10)

1 In the **Home** toolbar, click  **Functions** and choose **Global > Interpolation**.

2 In the **Settings** window for **Interpolation**, locate the **Definition** section.

3 From the **Data source** list, choose **File**.

4 Click  **Browse**.

5 Browse to the model's Application Libraries folder and double-click the file chamber_music_hall_T20.txt.

6 Click  **Import**.

7 In the **Function name** text field, type T20_meas.

8 Locate the **Interpolation and Extrapolation** section. From the **Interpolation** list, choose **Nearest neighbor**.

9 Locate the **Units** section. In the **Function** table, enter the following settings:

Function	Unit
T20_meas	s

10 In the **Argument** table, enter the following settings:

Argument	Unit
Column I	Hz

Interpolation 11 (int11)

1 In the **Home** toolbar, click  **Functions** and choose **Global > Interpolation**.

2 In the **Settings** window for **Interpolation**, locate the **Definition** section.

3 From the **Data source** list, choose **File**.

4 Click  **Browse**.

5 Browse to the model's Application Libraries folder and double-click the file chamber_music_hall_C80.txt.

6 Click  **Import**.

7 In the **Function name** text field, type C80_meas.

8 Locate the **Interpolation and Extrapolation** section. From the **Interpolation** list, choose **Nearest neighbor**.

9 Locate the **Units** section. In the **Function** table, enter the following settings:

Function	Unit
C80_meas	dB

10 In the **Argument** table, enter the following settings:

Argument	Unit
Column 1	Hz

Interpolation 12 (int12)

1 In the **Home** toolbar, click  **Functions** and choose **Global > Interpolation**.

2 In the **Settings** window for **Interpolation**, locate the **Definition** section.

3 From the **Data source** list, choose **File**.

4 Click  **Browse**.

5 Browse to the model's Application Libraries folder and double-click the file chamber_music_hall_D50.txt.

6 Click  **Import**.

7 In the **Function name** text field, type D50_meas.

8 Locate the **Interpolation and Extrapolation** section. From the **Interpolation** list, choose **Nearest neighbor**.

9 Locate the **Units** section. In the **Function** table, enter the following settings:



Function	Unit
D50_meas	%

10 In the **Argument** table, enter the following settings:


Argument	Unit
Column 1	Hz

Import the geometry and add the receivers.


GEOMETRY I

- 1 In the **Geometry** toolbar, click  **Insert Sequence**.
- 2 Browse to the model's Application Libraries folder and double-click the file `chamber_music_hall_geom_sequence.mph`.
- 3 In the **Geometry** toolbar, click  **Build All**.

Sphere 1 (sph1)

- 1 In the **Geometry** toolbar, click  **Sphere**.
- 2 In the **Settings** window for **Sphere**, locate the **Object Type** section.
- 3 From the **Type** list, choose **Surface**.
- 4 Locate the **Size** section. In the **Radius** text field, type `r_rec`.
- 5 Locate the **Position** section. In the **x** text field, type `x_r1`.
- 6 In the **y** text field, type `y_r1`.
- 7 In the **z** text field, type `z_r1`.
- 8 Locate the **Selections of Resulting Entities** section. Select the **Resulting objects selection** checkbox.
- 9 From the **Show in physics** list, choose **Boundary selection**.
- 10 Find the **Cumulative selection** subsection. Click **New**.
- 11 In the **New Cumulative Selection** dialog, type `All receivers` in the **Name** text field.
- 12 Click **OK**.

Sphere 2 (sph2)

- 1 Right-click **Sphere 1 (sph1)** and choose **Duplicate** to create the second receiver, then enter its correct coordinates. Repeat this operation for all the receivers needed.
- 2 In the **Geometry** toolbar, click  **Build All**.
Disable the analysis of the geometry as the remaining small geometric details can be kept.
- 3 In the **Model Builder** window, click **Geometry I**.
- 4 In the **Settings** window for **Geometry**, locate the **Cleanup** section.
- 5 Clear the **Automatic detection of small details** checkbox.
Now set up the ray acoustics simulation. The first physics interface will be used for a general single-frequency study where the whole solution data will be saved.

RAY ACOUSTICS (RAC)

- 1 In the **Model Builder** window, under **Component 1 (comp1)** click **Ray Acoustics (rac)**.


- 2 In the **Settings** window for **Ray Acoustics**, locate the **Material Properties of Exterior and Unmeshed Domains** section.
- 3 In the c_{ext} text field, type $c0$.
- 4 In the ρ_{ext} text field, type $\rho0$.
- 5 In the α_{ext} text field, type $a_{\text{air}}(f0)$.

Ray Properties I


- 1 In the **Model Builder** window, expand the **Ray Acoustics (rac)** node, then click **Ray Properties I**.
- 2 In the **Settings** window for **Ray Properties**, locate the **Ray Properties** section.
- 3 In the f text field, type $f0$.

Define the boundary conditions with the imported absorption and scattering coefficients.


Wall - Plaster

- 1 In the **Physics** toolbar, click  **Boundaries** and choose **Wall**.
- 2 In the **Settings** window for **Wall**, type **Wall - Plaster** in the **Label** text field.
- 3 Locate the **Boundary Selection** section. From the **Selection** list, choose **Plaster**.
- 4 Locate the **Wall Condition** section. In the s text field, type $s_{\text{plaster}}(f0)$.
- 5 In the α text field, type $a_{\text{plaster}}(f0)$.


Wall - Stage Panels

- 1 In the **Physics** toolbar, click  **Boundaries** and choose **Wall**.
- 2 In the **Settings** window for **Wall**, type **Wall - Stage Panels** in the **Label** text field.
- 3 Locate the **Boundary Selection** section. From the **Selection** list, choose **Stage panels**.
- 4 Locate the **Wall Condition** section. In the s text field, type $s_{\text{stagepanels}}(f0)$.
- 5 In the α text field, type $a_{\text{stagepanels}}(f0)$.


Wall - Windows

- 1 In the **Physics** toolbar, click  **Boundaries** and choose **Wall**.
- 2 In the **Settings** window for **Wall**, type **Wall - Windows** in the **Label** text field.
- 3 Locate the **Boundary Selection** section. From the **Selection** list, choose **Windows**.
- 4 Locate the **Wall Condition** section. In the s text field, type $s_{\text{windows}}(f0)$.
- 5 In the α text field, type $a_{\text{windows}}(f0)$.


Wall - Seating

- 1 In the **Physics** toolbar, click  **Boundaries** and choose **Wall**.
- 2 In the **Settings** window for **Wall**, type Wall - Seating in the **Label** text field.
- 3 Locate the **Boundary Selection** section. From the **Selection** list, choose **Seating**.
- 4 Locate the **Wall Condition** section. In the s text field, type $s_seating(f0)$.
- 5 In the α text field, type $a_seating(f0)$.


Wall - Floor

- 1 In the **Physics** toolbar, click  **Boundaries** and choose **Wall**.
- 2 In the **Settings** window for **Wall**, type Wall - Floor in the **Label** text field.
- 3 Locate the **Boundary Selection** section. From the **Selection** list, choose **Floor**.
- 4 Locate the **Wall Condition** section. In the s text field, type $s_floor(f0)$.
- 5 In the α text field, type $a_floor(f0)$.

Wall - Ceiling


- 1 In the **Physics** toolbar, click  **Boundaries** and choose **Wall**.
- 2 In the **Settings** window for **Wall**, type Wall - Ceiling in the **Label** text field.
- 3 Locate the **Boundary Selection** section. From the **Selection** list, choose **Ceiling**.
- 4 Locate the **Wall Condition** section. In the s text field, type $s_ceiling(f0)$.
- 5 In the α text field, type $a_ceiling(f0)$.

Wall - Structured Plaster

- 1 In the **Physics** toolbar, click  **Boundaries** and choose **Wall**.
- 2 In the **Settings** window for **Wall**, type Wall - Structured Plaster in the **Label** text field.
- 3 Locate the **Boundary Selection** section. From the **Selection** list, choose **Structured plaster**.
- 4 Locate the **Wall Condition** section. In the s text field, type $s_structuredplaster(f0)$.
- 5 In the α text field, type $a_structuredplaster(f0)$.

Enter the source and ray properties.

Source with Directivity I

- 1 In the **Physics** toolbar, click  **Global** and choose **Source with Directivity**.
- 2 In the **Settings** window for **Source with Directivity**, locate the **Initial Position** section.

3 Specify the \mathbf{q}_0 vector as

x_s1	x
y_s1	y
z_s1	z

4 Locate the **Ray Direction Vector** section. In the N_w text field, type Nrays.

5 Locate the **Intensity and Power** section. From the **Directivity** list, choose **Specify total source power**.

6 In the P_{src} text field, type P0.

Source with Directivity 2

1 Right-click **Source with Directivity 1** and choose **Duplicate**.

2 In the **Settings** window for **Source with Directivity**, locate the **Initial Position** section.

3 Specify the \mathbf{q}_0 vector as

x_s2	x
y_s2	y
z_s2	z

Define the spatial and power termination criteria. The given expression for threshold power ensures consistent termination with regards to the source parameters.

Ray Termination 1

1 In the **Physics** toolbar, click  **Global** and choose **Ray Termination**.

2 In the **Settings** window for **Ray Termination**, locate the **Termination Criteria** section.

3 From the **Spatial extents of ray propagation** list, choose **Bounding box, from geometry**.

4 From the **Additional termination criteria** list, choose **Power**.

5 In the Q_{th} text field, type $P0/Nrays*1e-7$.

Add a second **Ray Acoustics** interface with receivers to avoid unnecessarily long postprocessing times. Only the data related to the receivers will be stored to reduce the size of the saved file.


6 In the **Model Builder** window, right-click **Ray Acoustics (rac)** and choose **Copy**.

RAY ACOUSTICS 2 (RAC2)

1 In the **Model Builder** window, right-click **Component 1 (comp1)** and choose **Paste Ray Acoustics**.

- 2 In the **Messages from Paste** dialog, click **OK**.
- 3 In the **Settings** window for **Ray Acoustics**, locate the **Ray Release and Propagation** section.
- 4 Select the **Only store receiver data and accumulated variables** checkbox.

Receiver 1

- 1 In the **Physics** toolbar, click  **Boundaries** and choose **Receiver**.
- 2 In the **Settings** window for **Receiver**, locate the **Boundary Selection** section.
- 3 From the **Selection** list, choose **Sphere 1**.

Repeat the operation for the 4 remaining receivers and remember to choose the correct sphere selection.

Now create the mesh. In ray tracing simulations for room acoustics, the mesh is only used to detect the collisions between rays and boundaries. Therefore, accuracy is not compromised with a coarse resolution.

In the present model you can disregard the warning messages in the mesh. They are due to small surfaces in the imported geometry that do not affect the ray tracing.

MESH 1

- 1 In the **Model Builder** window, under **Component 1 (comp1)** click **Mesh 1**.
- 2 In the **Settings** window for **Mesh**, locate the **Physics-Controlled Mesh** section.
- 3 From the **Element size** list, choose **Extremely coarse**.
- 4 Locate the **Sequence Type** section. From the list, choose **User-controlled mesh**.


Free Triangular 1

- 1 In the **Model Builder** window, under **Component 1 (comp1) > Mesh 1** click **Free Triangular 1**.
- 2 In the **Settings** window for **Free Triangular**, locate the **Boundary Selection** section.
- 3 From the **Selection** list, choose **All boundaries**.

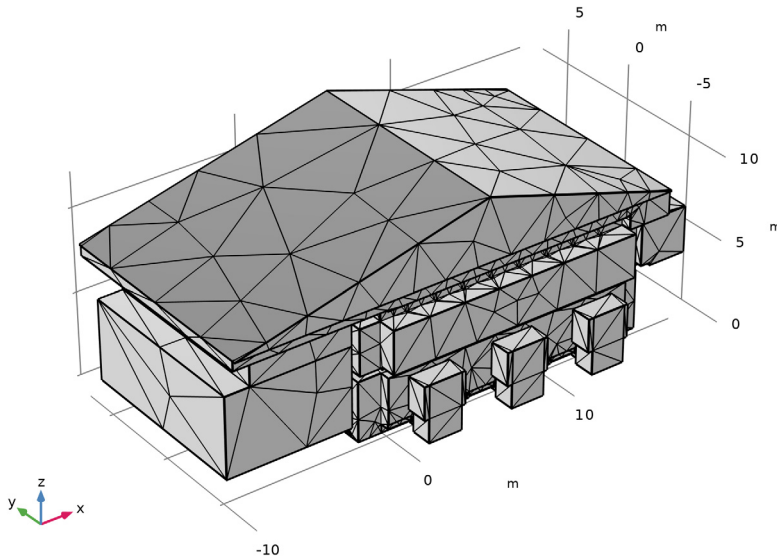
The receivers need a finer mesh to work properly. The recommended element size is 1/3 of the receiver radius.

Size 1

- 1 Right-click **Free Triangular 1** and choose **Size**.
- 2 In the **Settings** window for **Size**, locate the **Geometric Entity Selection** section.
- 3 From the **Selection** list, choose **All receivers**.
- 4 Locate the **Element Size** section. Click the **Custom** button.

- 5 Locate the **Element Size Parameters** section.
- 6 Select the **Maximum element size** checkbox. In the associated text field, type $r_{rec}/3$.
- 7 Click  **Build All**.

The mesh should look like this.





Create a study for the first physics interface that will calculate single-frequency ray trajectories.

STUDY 1 - SINGLE FREQUENCY

- 1 In the **Model Builder** window, click **Study 1**.
- 2 In the **Settings** window for **Study**, type Study 1 - Single Frequency in the **Label** text field.

Step 1: Ray Tracing

- 1 In the **Model Builder** window, under **Study 1 - Single Frequency** click **Step 1: Ray Tracing**.
- 2 In the **Settings** window for **Ray Tracing**, locate the **Study Settings** section.
- 3 From the **Time unit** list, choose **s**.
- 4 In the **Output times** text field, type 0 2.
- 5 Locate the **Physics and Variables Selection** section. Select the **Modify model configuration for study step** checkbox.

- 6 In the tree, select **Component 1 (comp1) > Ray Acoustics (rac) > Source with Directivity 2**.
- 7 Right-click and choose **Disable**.
- 8 In the tree, select **Component 1 (comp1) > Ray Acoustics 2 (rac2)**.
- 9 Click  **Disable in Model**.
- 10 In the **Study** toolbar, click  **Compute**.

RESULTS

Ray Trajectories (rac)


- 1 In the **Settings** window for **3D Plot Group**, locate the **Data** section.
- 2 From the **Time (s)** list, choose **Interpolation**.
- 3 In the **Time** text field, type 0.01.

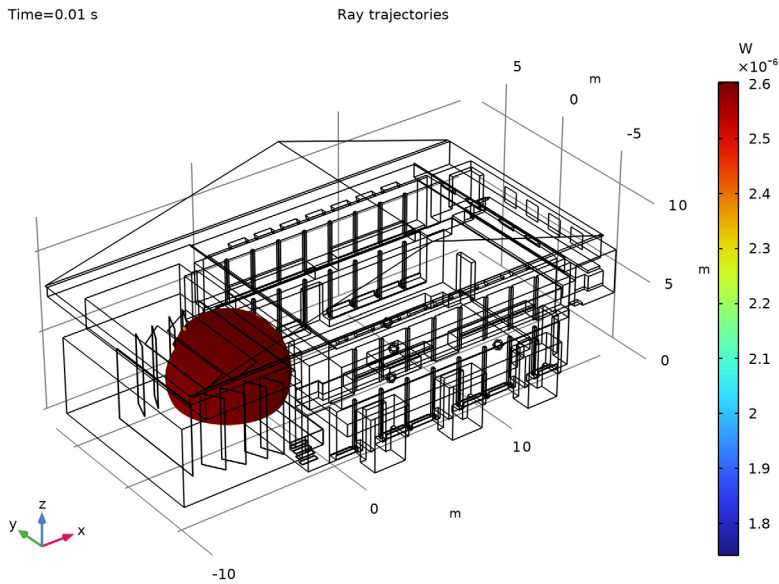
Ray Trajectories 1

- 1 In the **Model Builder** window, expand the **Ray Trajectories (rac)** node, then click **Ray Trajectories 1**.
- 2 In the **Settings** window for **Ray Trajectories**, locate the **Coloring and Style** section.
- 3 Find the **Line style** subsection. From the **Type** list, choose **None**.
- 4 Find the **Point style** subsection. From the **Type** list, choose **Point**.

Color Expression 1


- 1 In the **Model Builder** window, expand the **Ray Trajectories 1** node, then click **Color Expression 1**.
- 2 In the **Settings** window for **Color Expression**, locate the **Expression** section.
- 3 In the **Expression** text field, type `rac.Q`.

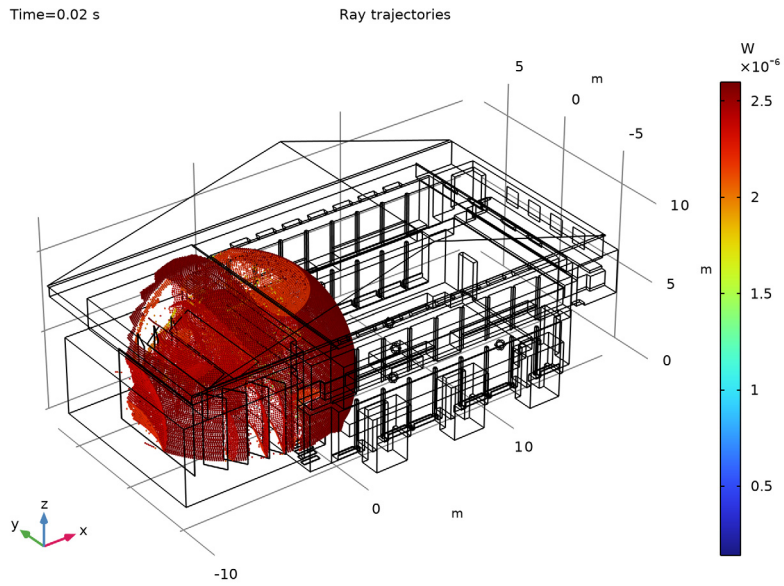
4 In the **Ray Trajectories (rac)** toolbar, click  **Plot**.



Ray Trajectories (rac)


- 1 In the **Model Builder** window, under **Results** click **Ray Trajectories (rac)**.
- 2 In the **Settings** window for **3D Plot Group**, locate the **Data** section.
- 3 In the **Time** text field, type 0.02.

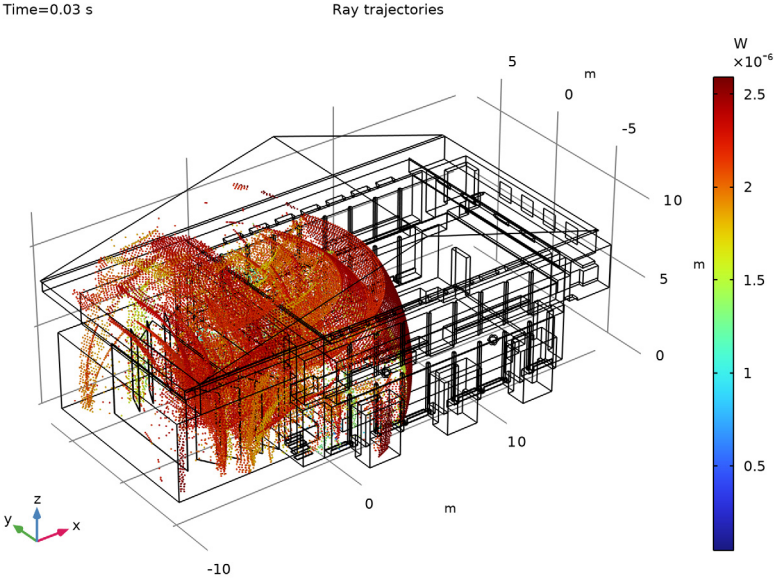
4 In the **Ray Trajectories (rac)** toolbar, click  **Plot**.



5 In the **Model Builder** window, click **Ray Trajectories (rac)**.


6 In the **Time** text field, type 0.03.

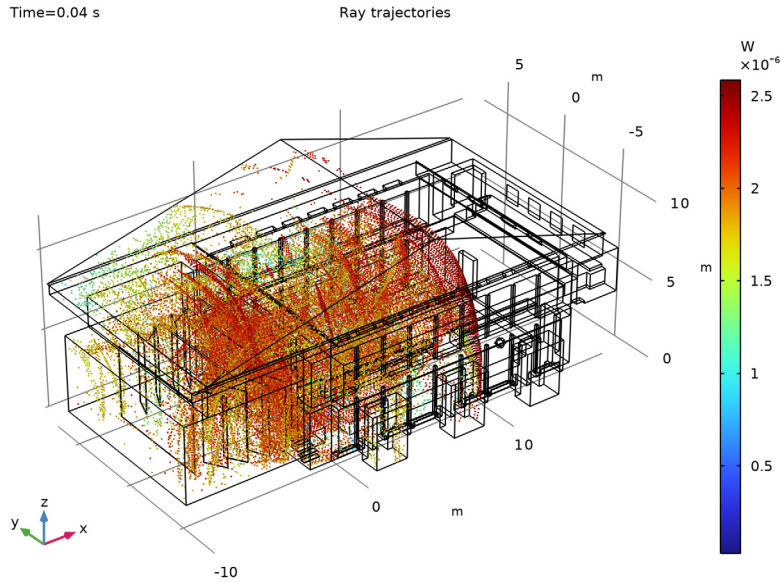
7 In the **Ray Trajectories (rac)** toolbar, click  **Plot**.



8 In the **Model Builder** window, click **Ray Trajectories (rac)**.



9 In the **Time** text field, type 0.04.

10 In the **Ray Trajectories (rac)** toolbar, click  **Plot**.



Now create one study for each source position in the second physics interface.


ADD STUDY

- 1 In the **Home** toolbar, click  **Add Study** to open the **Add Study** window.
- 2 Go to the **Add Study** window.
- 3 Find the **Studies** subsection. In the **Select Study** tree, select **Preset Studies for Selected Physics Interfaces > Ray Tracing**.
- 4 Click the **Add Study** button in the window toolbar.
- 5 In the **Home** toolbar, click  **Add Study** to close the **Add Study** window.

STUDY 2 - SOURCE 1

In the **Settings** window for **Study**, type Study 2 - Source 1 in the **Label** text field.

Parametric Sweep

- 1 In the **Study** toolbar, click  **Parametric Sweep**.
- 2 In the **Settings** window for **Parametric Sweep**, locate the **Study Settings** section.
- 3 Click **+ Add**.

4 In the table, enter the following settings:

Parameter name	Parameter value list	Parameter unit
f0 (Band center frequency)		Hz

5 In the table, click to select the cell at row number 1 and column number 2.

6 Click  **Range**.

7 In the **Range** dialog, choose **ISO preferred frequencies** from the **Entry method** list.

8 In the **Start frequency** text field, type 100.

9 In the **Stop frequency** text field, type 5000.

10 From the **Interval** list, choose **1/3 octave**.

11 Click **Replace**.

Step 1: Ray Tracing

1 In the **Model Builder** window, click **Step 1: Ray Tracing**.

2 In the **Settings** window for **Ray Tracing**, locate the **Study Settings** section.

3 From the **Time unit** list, choose **s**.

4 In the **Output times** text field, type 0 2.

5 Locate the **Physics and Variables Selection** section. Select the **Modify model configuration for study step** checkbox.

6 In the tree, select **Component 1 (comp1) > Ray Acoustics (rac)**.

7 Click  **Disable in Model**.

8 In the tree, select **Component 1 (comp1) > Ray Acoustics 2 (rac2) > Source with Directivity 2**.

9 Right-click and choose **Disable**.

ADD STUDY

1 In the **Study** toolbar, click  **Add Study** to open the **Add Study** window.

2 Go to the **Add Study** window.

3 Find the **Studies** subsection. In the **Select Study** tree, select **Preset Studies for Selected Physics Interfaces > Ray Tracing**.



4 Click the **Add Study** button in the window toolbar.

5 In the **Study** toolbar, click  **Add Study** to close the **Add Study** window.


STUDY 3 - SOURCE 2

In the **Settings** window for **Study**, type Study 3 - Source 2 in the **Label** text field.



Parametric Sweep

- 1 In the **Study** toolbar, click  **Parametric Sweep**.
- 2 In the **Settings** window for **Parametric Sweep**, locate the **Study Settings** section.
- 3 Click  **Add**.
- 4 In the table, enter the following settings:

Parameter name	Parameter value list	Parameter unit
f0 (Band center frequency)		Hz

- 5 In the table, click to select the cell at row number 1 and column number 2.
- 6 Click  **Range**.
- 7 In the **Range** dialog, choose **ISO preferred frequencies** from the **Entry method** list.
- 8 In the **Start frequency** text field, type 100.
- 9 In the **Stop frequency** text field, type 5000.
- 10 From the **Interval** list, choose **1/3 octave**.
- 11 Click **Replace**.

Step 1: Ray Tracing

- 1 In the **Model Builder** window, click **Step 1: Ray Tracing**.
- 2 In the **Settings** window for **Ray Tracing**, locate the **Study Settings** section.
- 3 From the **Time unit** list, choose **s**.
- 4 In the **Output times** text field, type 0 2.
- 5 Locate the **Physics and Variables Selection** section. Select the **Modify model configuration for study step** checkbox.
- 6 In the tree, select **Component 1 (comp1) > Ray Acoustics (rac)**.
- 7 Click  **Disable in Model**.
- 8 In the tree, select **Component 1 (comp1) > Ray Acoustics 2 (rac2) > Source with Directivity 1**.
- 9 Click  **Disable**.



Make sure to select the following options to facilitate your workflow. All the results will be rendered after the model has solved. Rendering of all 10 impulse responses with 18 1/3-octave bands takes around 45 minutes depending on your hardware. Moreover,

the size of the saved file can be very large due to the many impulse responses calculated and stored. To save some disk space, set the saving preferences to optimize for file size.

RESULTS




- 1 In the **Model Builder** window, click **Results**.
- 2 In the **Settings** window for **Results**, locate the **Update of Results** section.
- 3 Select the **Only plot when requested** checkbox.
- 4 Select the **Recompute all plot data after solving** checkbox.
- 5 Locate the **Save Data in the Model** section. From the **Save plot data** list, choose **On**.
Add study references to compute both studies at once.

ADD STUDY

- 1 In the **Home** toolbar, click  **Add Study** to open the **Add Study** window.
- 2 Go to the **Add Study** window.
- 3 Find the **Studies** subsection. In the **Select Study** tree, select **Empty Study**.
- 4 Click the **Add Study** button in the window toolbar.
- 5 In the **Home** toolbar, click  **Add Study** to close the **Add Study** window.

STUDY 4

No Study

- 1 In the **Study** toolbar, click  **More Study Extensions** and choose **Study Reference**.
- 2 In the **Settings** window for **Study Reference**, locate the **Study Reference** section.
- 3 From the **Study reference** list, choose **Study 2 - Source 1**.
- 4 In the **Study** toolbar, click  **More Study Extensions** and choose **Study Reference**.
- 1 In the **Settings** window for **Study Reference**, locate the **Study Reference** section.
- 2 From the **Study reference** list, choose **Study 3 - Source 2**.
- 3 In the **Study** toolbar, click  **Compute**.

Reassign the solutions associated to the datasets for Ray 2 and Ray 3 to match with Study 2 and Study 3.

RESULTS

Ray 2

- 1 In the **Model Builder** window, expand the **Results > Datasets** node, then click **Ray 2**.
- 2 In the **Settings** window for **Ray**, locate the **Ray Solution** section.

3 From the **Solution** list, choose **Parametric Solutions 1 (sol5)**.

Ray 3

- 1 In the **Model Builder** window, click **Ray 3**.
- 2 In the **Settings** window for **Ray**, locate the **Ray Solution** section.
- 3 From the **Solution** list, choose **Parametric Solutions 2 (sol6)**.

Next, label the datasets corresponding to the 10 source-receiver pairs.


Receiver 3D 1_1

- 1 In the **Model Builder** window, click **Receiver 3D 1**.
 - 2 In the **Settings** window for **Receiver 3D**, type Receiver 3D 1_1 in the **Label** text field.
- Repeat the previous operation for all receiver datasets related to the same study.


Receiver 3D 2_1

- 1 In the **Model Builder** window, under **Results > Datasets** click **Receiver 3D 6**.
 - 2 In the **Settings** window for **Receiver 3D**, type Receiver 3D 2_1 in the **Label** text field.
- Repeat this operation for the 4 remaining receiver datasets.
- Set up the impulse responses corresponding to the datasets previously created, plot the level decay curves using the **Energy Decay** subfeature, and compute the desired room acoustic parameters.

Impulse response 1_1


- 1 In the **Results** toolbar, click  **ID Plot Group**.
- 2 In the **Settings** window for **ID Plot Group**, type Impulse response 1_1 in the **Label** text field.
- 3 Locate the **Data** section. From the **Dataset** list, choose **Receiver 3D 1_1**.
- 4 Locate the **Legend** section. From the **Position** list, choose **Lower left**.


Impulse Response 1

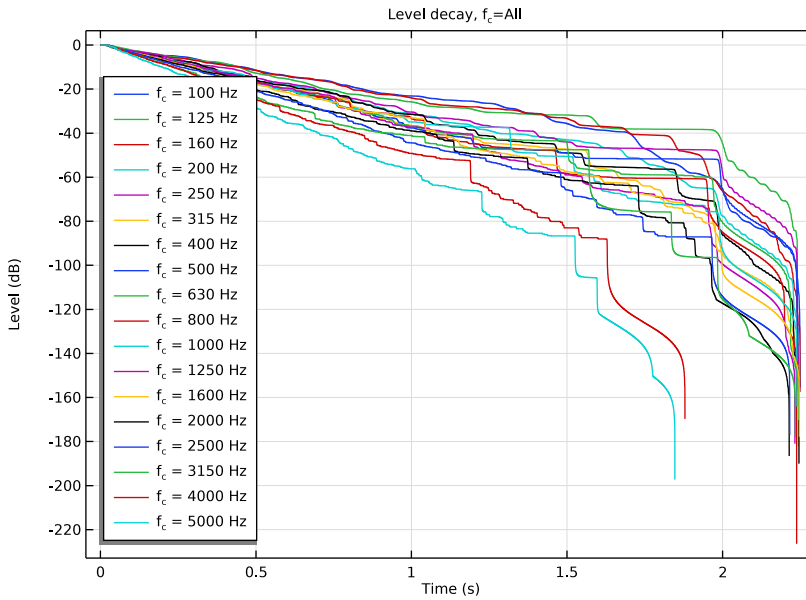
- 1 In the **Impulse response 1_1** toolbar, click  **More Plots** and choose **Impulse Response**.
- 2 In the **Settings** window for **Impulse Response**, locate the **Data** section.
- 3 From the **Frequency interpretation** list, choose **1/3 octave**.
- 4 Locate the **Expression** section. In the **Frequency** text field, type $rac2.f$.
- 5 In the **Power** text field, type $rac2.Q$.
- 6 In the **Density** text field, type $rac2.rho$.
- 7 In the **Speed of sound** text field, type $rac2.c$.

- 8 In the **Number of reflections** text field, type `rac2.Nref1`.
- 9 Click to expand the **Legends** section. Select the **Show legends** checkbox.


Energy Decay I

- 1 Right-click **Impulse Response I** and choose **Energy Decay**.
- 2 In the **Settings** window for **Energy Decay**, locate the **Display** section.
- 3 From the **Band type** list, choose **Individual bands**.
- 4 From the **Plot** list, choose **Level decay**.
- 5 Locate the **Table** section. Find the **Early energy** subsection. Clear the **C₅₀**, **Clarity** checkbox.
- 6 Clear the **t_r**, **First ray arrival time** checkbox.
- 7 Clear the **t_s**, **Center time** checkbox.
- 8 Find the **Reverberation** subsection. Clear the **T₃₀** checkbox.
- 9 Clear the **T₆₀** checkbox.
- 10 Find the **Speech intelligibility** subsection. Clear the **SNR**, **Apparent SNR** checkbox.
- 11 Clear the **STI**, **Speech transmission index** checkbox.
- 12 In the **Impulse response I_I** toolbar, click  **Plot**.
- 13 Locate the **Display** section. From the **Band frequency** list, choose **All frequencies**.

14 In the **Impulse response I_1** toolbar, click  **Plot**.



Impulse response I_2

- 1 In the **Model Builder** window, right-click **Impulse response I_1** and choose **Duplicate**.
- 2 In the **Settings** window for **ID Plot Group**, type **Impulse response 1_2** in the **Label** text field.
- 3 Locate the **Data** section. From the **Dataset** list, choose **Receiver 3D I_2**.
- 4 In the **Impulse response I_2** toolbar, click  **Plot**.

Repeat the duplication and dataset selection operations to create the impulse responses corresponding to the 8 remaining source-receiver pairs.

Impulse response I_1, Impulse response I_2, Impulse response I_3, Impulse response I_4, Impulse response I_5, Impulse response 2_1, Impulse response 2_2, Impulse response 2_3, Impulse response 2_4, Impulse response 2_5

- 1 In the **Model Builder** window, under **Results**, Ctrl-click to select **Impulse response I_1**, **Impulse response I_2**, **Impulse response I_3**, **Impulse response I_4**, **Impulse response I_5**, **Impulse response 2_1**, **Impulse response 2_2**, **Impulse response 2_3**, **Impulse response 2_4**, and **Impulse response 2_5**.
- 2 Right-click and choose **Group**.

Impulse responses

- 1 In the **Settings** window for **Group**, type Impulse responses in the **Label** text field.
Rename the result tables to match with their corresponding impulse responses. Repeat the following steps accordingly for the ten tables.

Objective Quality Metrics 1_1

- 1 In the **Model Builder** window, expand the **Results > Tables** node, then click **Objective Quality Metrics**.
- 2 In the **Settings** window for **Table**, type Objective Quality Metrics 1_1 in the **Label** text field.


Objective Quality Metrics 2_1

- 1 In the **Model Builder** window, under **Results > Tables** click **Objective Quality Metrics 5**.
- 2 In the **Settings** window for **Table**, type Objective Quality Metrics 2_1 in the **Label** text field.

Now that the impulse responses of the different source-receiver pairs have been computed, interpolate the resulting acoustic parameters for postprocessing.

GLOBAL DEFINITIONS

Interpolation 13 (int13)


- 1 In the **Home** toolbar, click  **Functions** and choose **Global > Interpolation**.
- 2 In the **Settings** window for **Interpolation**, locate the **Definition** section.
- 3 From the **Data source** list, choose **Result table**.
- 4 Locate the **Data Column Settings** section. In the table, enter the following settings:

Columns	Type	Settings
C80 (dB)	Function values	Function name=int13a
EDT (s)	Function values	Function name=int13b
T20 (s)	Function values	Function name=int13c

- 5 In the table, click to select the cell at row number 1 and column number 1.
- 6 In the **Unit** text field, type Hz.
- 7 In the table, click to select the cell at row number 2 and column number 1.
- 8 In the **Name** text field, type D50_11.
- 9 In the **Unit** text field, type %.
- 10 In the table, click to select the cell at row number 3 and column number 1.

- 11 In the **Name** text field, type C80_11.
- 12 In the **Unit** text field, type dB.
- 13 In the table, click to select the cell at row number 4 and column number 1.
- 14 In the **Name** text field, type EDT_11.
- 15 In the **Unit** text field, type s.
- 16 In the table, click to select the cell at row number 5 and column number 1.
- 17 In the **Name** text field, type T20_11.
- 18 In the **Unit** text field, type s.
- 19 Locate the **Interpolation and Extrapolation** section. From the **Interpolation** list, choose **Nearest neighbor**.

Interpolation 14 (int14)

- 1 In the **Home** toolbar, click  **Functions** and choose **Global > Interpolation**.
- 2 In the **Settings** window for **Interpolation**, locate the **Definition** section.
- 3 From the **Data source** list, choose **Result table**.
- 4 From the **Table from** list, choose **Objective Quality Metrics 1_2**.
- 5 Locate the **Data Column Settings** section. In the table, enter the following settings:

Columns	Type	Settings
C80 (dB)	Function values	Function name=int14a
EDT (s)	Function values	Function name=int14b
T20 (s)	Function values	Function name=int14c

- 6 In the table, click to select the cell at row number 1 and column number 1.
- 7 In the **Unit** text field, type Hz.
- 8 In the table, click to select the cell at row number 2 and column number 1.
- 9 In the **Name** text field, type D50_12.
- 10 In the **Unit** text field, type %.
- 11 In the table, click to select the cell at row number 3 and column number 1.
- 12 In the **Name** text field, type C80_12.
- 13 In the **Unit** text field, type dB.
- 14 In the table, click to select the cell at row number 4 and column number 1.
- 15 In the **Name** text field, type EDT_12.
- 16 In the **Unit** text field, type s.

- 17 In the table, click to select the cell at row number 5 and column number 1.
- 18 In the **Name** text field, type T20_12.
- 19 In the **Unit** text field, type s.
- 20 Locate the **Interpolation and Extrapolation** section. From the **Interpolation** list, choose **Nearest neighbor**.

Interpolation 15 (int15)

- 1 In the **Home** toolbar, click **f(∞) Functions** and choose **Global > Interpolation**.
- 2 In the **Settings** window for **Interpolation**, locate the **Definition** section.
- 3 From the **Data source** list, choose **Result table**.
- 4 From the **Table from** list, choose **Objective Quality Metrics 1_3**.
- 5 Locate the **Data Column Settings** section. In the table, enter the following settings:

Columns	Type	Settings
C80 (dB)	Function values	Function name=int15a
EDT (s)	Function values	Function name=int15b
T20 (s)	Function values	Function name=int15c

- 6 In the table, click to select the cell at row number 1 and column number 1.
- 7 In the **Unit** text field, type Hz.
- 8 In the table, click to select the cell at row number 2 and column number 1.
- 9 In the **Name** text field, type D50_13.
- 10 In the **Unit** text field, type %.
- 11 In the table, click to select the cell at row number 3 and column number 1.
- 12 In the **Name** text field, type C80_13.
- 13 In the **Unit** text field, type dB.
- 14 In the table, click to select the cell at row number 4 and column number 1.
- 15 In the **Name** text field, type EDT_13.
- 16 In the **Unit** text field, type s.
- 17 In the table, click to select the cell at row number 5 and column number 1.
- 18 In the **Name** text field, type T20_13.
- 19 In the **Unit** text field, type s.
- 20 Locate the **Interpolation and Extrapolation** section. From the **Interpolation** list, choose **Nearest neighbor**.

Interpolation 16 (int16)

- 1 In the **Home** toolbar, click **f(x) Functions** and choose **Global > Interpolation**.
- 2 In the **Settings** window for **Interpolation**, locate the **Definition** section.
- 3 From the **Data source** list, choose **Result table**.
- 4 From the **Table from** list, choose **Objective Quality Metrics 1_4**.
- 5 Locate the **Data Column Settings** section. In the table, enter the following settings:

Columns	Type	Settings
C80 (dB)	Function values	Function name=int16a
EDT (s)	Function values	Function name=int16b
T20 (s)	Function values	Function name=int16c

- 6 In the table, click to select the cell at row number 1 and column number 1.
- 7 In the **Unit** text field, type Hz.
- 8 In the table, click to select the cell at row number 2 and column number 1.
- 9 In the **Name** text field, type D50_14.
- 10 In the **Unit** text field, type %.
- 11 In the table, click to select the cell at row number 3 and column number 1.
- 12 In the **Name** text field, type C80_14.
- 13 In the **Unit** text field, type dB.
- 14 In the table, click to select the cell at row number 4 and column number 1.
- 15 In the **Name** text field, type EDT_14.
- 16 In the **Unit** text field, type s.
- 17 In the table, click to select the cell at row number 5 and column number 1.
- 18 In the **Name** text field, type T20_14.
- 19 In the **Unit** text field, type s.
- 20 Locate the **Interpolation and Extrapolation** section. From the **Interpolation** list, choose **Nearest neighbor**.

Interpolation 17 (int17)

- 1 In the **Home** toolbar, click **f(x) Functions** and choose **Global > Interpolation**.
- 2 In the **Settings** window for **Interpolation**, locate the **Definition** section.
- 3 From the **Data source** list, choose **Result table**.
- 4 From the **Table from** list, choose **Objective Quality Metrics 1_5**.

5 Locate the **Data Column Settings** section. In the table, enter the following settings:

Columns	Type	Settings
C80 (dB)	Function values	Function name=int17a
EDT (s)	Function values	Function name=int17b
T20 (s)	Function values	Function name=int17c

6 In the table, click to select the cell at row number 1 and column number 1.

7 In the **Unit** text field, type Hz.

8 In the table, click to select the cell at row number 2 and column number 1.

9 In the **Name** text field, type D50_15.

10 In the **Unit** text field, type %.

11 In the table, click to select the cell at row number 3 and column number 1.

12 In the **Name** text field, type C80_15.

13 In the **Unit** text field, type dB.

14 In the table, click to select the cell at row number 4 and column number 1.

15 In the **Name** text field, type EDT_15.

16 In the **Unit** text field, type s.

17 In the table, click to select the cell at row number 5 and column number 1.

18 In the **Name** text field, type T20_15.

19 In the **Unit** text field, type s.

20 Locate the **Interpolation and Extrapolation** section. From the **Interpolation** list, choose **Nearest neighbor**.

Interpolation 18 (int18)

1 In the **Home** toolbar, click  **Functions** and choose **Global > Interpolation**.

2 In the **Settings** window for **Interpolation**, locate the **Definition** section.

3 From the **Data source** list, choose **Result table**.


4 From the **Table from** list, choose **Objective Quality Metrics 2_1**.

5 Locate the **Data Column Settings** section. In the table, enter the following settings:

Columns	Type	Settings
C80 (dB)	Function values	Function name=int18a
EDT (s)	Function values	Function name=int18b
T20 (s)	Function values	Function name=int18c

- 6 In the table, click to select the cell at row number 1 and column number 1.
- 7 In the **Unit** text field, type Hz.
- 8 In the table, click to select the cell at row number 2 and column number 1.
- 9 In the **Name** text field, type D50_21.
- 10 In the **Unit** text field, type %.
- 11 In the table, click to select the cell at row number 3 and column number 1.
- 12 In the **Name** text field, type C80_21.
- 13 In the **Unit** text field, type dB.
- 14 In the table, click to select the cell at row number 4 and column number 1.
- 15 In the **Name** text field, type EDT_21.
- 16 In the **Unit** text field, type s.
- 17 In the table, click to select the cell at row number 5 and column number 1.
- 18 In the **Name** text field, type T20_21.
- 19 In the **Unit** text field, type s.
- 20 Locate the **Interpolation and Extrapolation** section. From the **Interpolation** list, choose **Nearest neighbor**.

Interpolation 19 (int19)

- 1 In the **Home** toolbar, click  **Functions** and choose **Global > Interpolation**.
- 2 In the **Settings** window for **Interpolation**, locate the **Definition** section.
- 3 From the **Data source** list, choose **Result table**.
- 4 From the **Table from** list, choose **Objective Quality Metrics 2_2**.
- 5 Locate the **Data Column Settings** section. In the table, enter the following settings:

Columns	Type	Settings
C80 (dB)	Function values	Function name=int19a
EDT (s)	Function values	Function name=int19b
T20 (s)	Function values	Function name=int19c

- 6 In the table, click to select the cell at row number 1 and column number 1.
- 7 In the **Unit** text field, type Hz.
- 8 In the table, click to select the cell at row number 2 and column number 1.
- 9 In the **Name** text field, type D50_22.
- 10 In the **Unit** text field, type %.

- 11 In the table, click to select the cell at row number 3 and column number 1.
- 12 In the **Name** text field, type C80_22.
- 13 In the **Unit** text field, type dB.
- 14 In the table, click to select the cell at row number 4 and column number 1.
- 15 In the **Name** text field, type EDT_22.
- 16 In the **Unit** text field, type s.
- 17 In the table, click to select the cell at row number 5 and column number 1.
- 18 In the **Name** text field, type T20_22.
- 19 In the **Unit** text field, type s.
- 20 Locate the **Interpolation and Extrapolation** section. From the **Interpolation** list, choose **Nearest neighbor**.

Interpolation 20 (int20)


- 1 In the **Home** toolbar, click **f(∞) Functions** and choose **Global > Interpolation**.
- 2 In the **Settings** window for **Interpolation**, locate the **Definition** section.
- 3 From the **Data source** list, choose **Result table**.
- 4 From the **Table from** list, choose **Objective Quality Metrics 2_3**.
- 5 Locate the **Data Column Settings** section. In the table, enter the following settings:

Columns	Type	Settings
C80 (dB)	Function values	Function name=int20a
EDT (s)	Function values	Function name=int20b
T20 (s)	Function values	Function name=int20c

- 6 In the table, click to select the cell at row number 1 and column number 1.
- 7 In the **Unit** text field, type Hz.
- 8 In the table, click to select the cell at row number 2 and column number 1.
- 9 In the **Name** text field, type D50_23.
- 10 In the **Unit** text field, type %.
- 11 In the table, click to select the cell at row number 3 and column number 1.
- 12 In the **Name** text field, type C80_23.
- 13 In the **Unit** text field, type dB.
- 14 In the table, click to select the cell at row number 4 and column number 1.
- 15 In the **Name** text field, type EDT_23.

- 16 In the **Unit** text field, type s.
- 17 In the table, click to select the cell at row number 5 and column number 1.
- 18 In the **Name** text field, type T20_23.
- 19 In the **Unit** text field, type s.
- 20 Locate the **Interpolation and Extrapolation** section. From the **Interpolation** list, choose **Nearest neighbor**.

Interpolation 21 (int21)

- 1 In the **Home** toolbar, click  **Functions** and choose **Global > Interpolation**.
- 2 In the **Settings** window for **Interpolation**, locate the **Definition** section.
- 3 From the **Data source** list, choose **Result table**.
- 4 From the **Table from** list, choose **Objective Quality Metrics 2_4**.
- 5 Locate the **Data Column Settings** section. In the table, enter the following settings:

Columns	Type	Settings
C80 (dB)	Function values	Function name=int21a
EDT (s)	Function values	Function name=int21b
T20 (s)	Function values	Function name=int21c

- 6 In the table, click to select the cell at row number 1 and column number 1.
- 7 In the **Unit** text field, type Hz.
- 8 In the table, click to select the cell at row number 2 and column number 1.
- 9 In the **Name** text field, type D50_24.
- 10 In the **Unit** text field, type %.
- 11 In the table, click to select the cell at row number 3 and column number 1.
- 12 In the **Name** text field, type C80_24.
- 13 In the **Unit** text field, type dB.
- 14 In the table, click to select the cell at row number 4 and column number 1.
- 15 In the **Name** text field, type EDT_24.
- 16 In the **Unit** text field, type s.
- 17 In the table, click to select the cell at row number 5 and column number 1.
- 18 In the **Name** text field, type T20_24.
- 19 In the **Unit** text field, type s.

20 Locate the **Interpolation and Extrapolation** section. From the **Interpolation** list, choose **Nearest neighbor**.

Interpolation 22 (int22)

1 In the **Home** toolbar, click  **Functions** and choose **Global > Interpolation**.

2 In the **Settings** window for **Interpolation**, locate the **Definition** section.

3 From the **Data source** list, choose **Result table**.

4 From the **Table from** list, choose **Objective Quality Metrics 2_5**.

5 Locate the **Data Column Settings** section. In the table, enter the following settings:

Columns	Type	Settings
C80 (dB)	Function values	Function name=int22a
EDT (s)	Function values	Function name=int22b
T20 (s)	Function values	Function name=int22c

6 In the table, click to select the cell at row number 1 and column number 1.

7 In the **Unit** text field, type Hz.

8 In the table, click to select the cell at row number 2 and column number 1.

9 In the **Name** text field, type D50_25.

10 In the **Unit** text field, type %.

11 In the table, click to select the cell at row number 3 and column number 1.

12 In the **Name** text field, type C80_25.

13 In the **Unit** text field, type dB.

14 In the table, click to select the cell at row number 4 and column number 1.

15 In the **Name** text field, type EDT_25.

16 In the **Unit** text field, type s.

17 In the table, click to select the cell at row number 5 and column number 1.

18 In the **Name** text field, type T20_25.


19 In the **Unit** text field, type s.

20 Locate the **Interpolation and Extrapolation** section. From the **Interpolation** list, choose **Nearest neighbor**.

Create an empty study to load the newly defined interpolation functions.

ADD STUDY



1 In the **Home** toolbar, click  **Add Study** to open the **Add Study** window.

- 2 Go to the **Add Study** window.
- 3 Find the **Studies** subsection. In the **Select Study** tree, select **Empty Study**.
- 4 Click the **Add Study** button in the window toolbar.
- 5 In the **Home** toolbar, click  **Add Study** to close the **Add Study** window.



STUDY 5 - EMPTY FOR POSTPROCESSING

- 1 In the **Settings** window for **Study**, type Study 5 - Empty for postprocessing in the **Label** text field.
- 2 Locate the **Study Settings** section. Clear the **Generate default plots** checkbox.

Parametric Sweep

- 1 In the **Study** toolbar, click  **Parametric Sweep**.
- 2 In the **Settings** window for **Parametric Sweep**, locate the **Study Settings** section.
- 3 Click  **Add**.
- 4 In the table, enter the following settings:


Parameter name	Parameter value list	Parameter unit
f0 (Band center frequency)		Hz

- 5 In the table, click to select the cell at row number 1 and column number 2.
- 6 Click  **Range**.
- 7 In the **Range** dialog, choose **ISO preferred frequencies** from the **Entry method** list.
- 8 In the **Start frequency** text field, type 100.
- 9 In the **Stop frequency** text field, type 5000.
- 10 From the **Interval** list, choose **1/3 octave**.
- 11 Click **Replace**.
- 12 In the **Study** toolbar, click  **Compute**.

Take the average of the acoustic parameters to obtain their values over the room.

RESULTS

Early Decay Time EDT

- 1 In the **Results** toolbar, click  **ID Plot Group**.
- 2 In the **Settings** window for **ID Plot Group**, type Early Decay Time EDT in the **Label** text field.

- 3 Locate the **Data** section. From the **Dataset** list, choose **Study 5 - Empty for postprocessing/Parametric Solutions 3 (sol44)**.
- 4 From the **Time selection** list, choose **First**.
- 5 Click to expand the **Title** section. From the **Title type** list, choose **Manual**.
- 6 In the **Title** text area, type Average over source-receiver pairs.
- 7 Locate the **Plot Settings** section.
- 8 Select the **x-axis label** checkbox. In the associated text field, type f (Hz).
- 9 Select the **y-axis label** checkbox. In the associated text field, type EDT (s).
- 10 Locate the **Axis** section. Select the **Manual axis limits** checkbox.
- 11 In the **x minimum** text field, type 95.
- 12 In the **x maximum** text field, type 5250.
- 13 In the **y minimum** text field, type 0.
- 14 In the **y maximum** text field, type 3.
- 15 Select the **x-axis log scale** checkbox.

Global 1

- 1 Right-click **Early Decay Time EDT** and choose **Global**.
- 2 In the **Settings** window for **Global**, locate the **y-Axis Data** section.
- 3 In the table, enter the following settings:

Expression	Unit	Description
EDT_meas (f0)	s	Interpolation 9
(EDT_11 (f0)+EDT_12 (f0)+EDT_13 (f0)+EDT_14 (f0)+EDT_15 (f0)+EDT_21 (f0)+EDT_22 (f0)+EDT_23 (f0)+EDT_24 (f0)+EDT_25 (f0)) / 10	s	

- 4 Locate the **x-Axis Data** section. From the **Axis source data** list, choose **f0**.
- 5 Click to expand the **Coloring and Style** section. Find the **Line style** subsection. From the **Line** list, choose **Dashed**.
- 6 Find the **Line markers** subsection. From the **Marker** list, choose **Circle**.
- 7 Click to expand the **Legends** section. From the **Legends** list, choose **Manual**.

8 In the table, enter the following settings:

Legends
Measurement
Calculation

Global 2

- 1 In the **Model Builder** window, right-click **Early Decay Time EDT** and choose **Global**.
- 2 In the **Settings** window for **Global**, locate the **y-Axis Data** section.
- 3 In the table, enter the following settings:

Expression	Unit	Description
$(1-3*0.05)*EDT_meas(f0)$	s	

- 4 Locate the **x-Axis Data** section. From the **Axis source data** list, choose **f0**.
- 5 Locate the **Coloring and Style** section. Find the **Line style** subsection. From the **Line** list, choose **Dotted**.
- 6 From the **Color** list, choose **Cycle (reset)**.
- 7 Locate the **Legends** section. From the **Legends** list, choose **Manual**.
- 8 In the table, enter the following settings:


Legends
3*JND interval

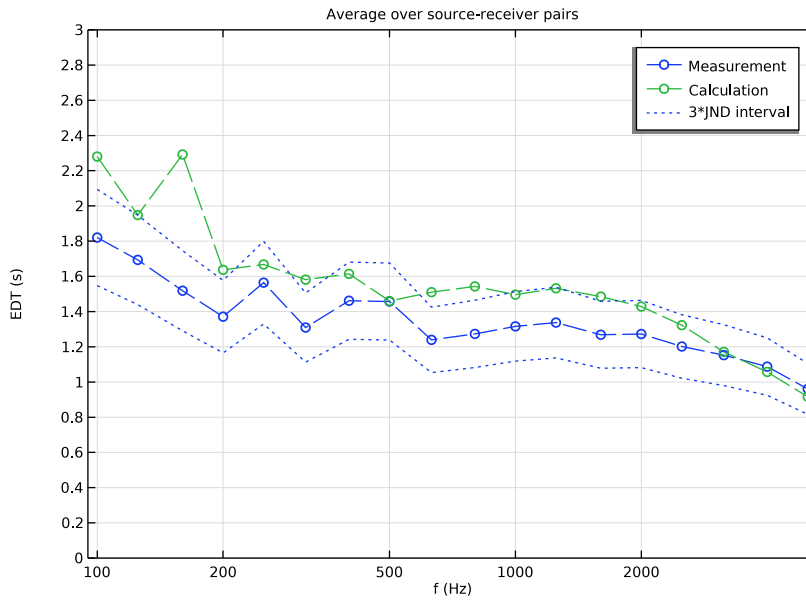
Global 3

- 1 Right-click **Early Decay Time EDT** and choose **Global**.
- 2 In the **Settings** window for **Global**, locate the **y-Axis Data** section.
- 3 In the table, enter the following settings:

Expression	Unit	Description
$(1+3*0.05)*EDT_meas(f0)$	s	

- 4 Locate the **x-Axis Data** section. From the **Axis source data** list, choose **f0**.
- 5 Locate the **Coloring and Style** section. Find the **Line style** subsection. From the **Line** list, choose **Dotted**.
- 6 From the **Color** list, choose **Cycle (reset)**.
- 7 Locate the **Legends** section. Clear the **Show legends** checkbox.

8 In the **Early Decay Time EDT** toolbar, click  **Plot**.



Reverberation Time T20

- 1 Right-click **Early Decay Time EDT** and choose **Duplicate**.
- 2 In the **Settings** window for **ID Plot Group**, type Reverberation Time T20 in the **Label** text field.
- 3 Locate the **Plot Settings** section. In the **y-axis label** text field, type T20 (s).

Global I

- 1 In the **Model Builder** window, expand the **Reverberation Time T20** node, then click **Global I**.
- 2 In the **Settings** window for **Global**, locate the **y-Axis Data** section.
- 3 In the table, enter the following settings:

Expression	Unit	Description
T20_meas (f0)	s	Interpolation 10
$(T20_{11}(f_0)+T20_{12}(f_0)+T20_{13}(f_0)+T20_{14}(f_0)+T20_{15}(f_0)+T20_{21}(f_0)+T20_{22}(f_0)+T20_{23}(f_0)+T20_{24}(f_0)+T20_{25}(f_0))/10$		

Global 2

- 1 In the **Model Builder** window, click **Global 2**.
- 2 In the **Settings** window for **Global**, locate the **y-Axis Data** section.
- 3 In the table, enter the following settings:

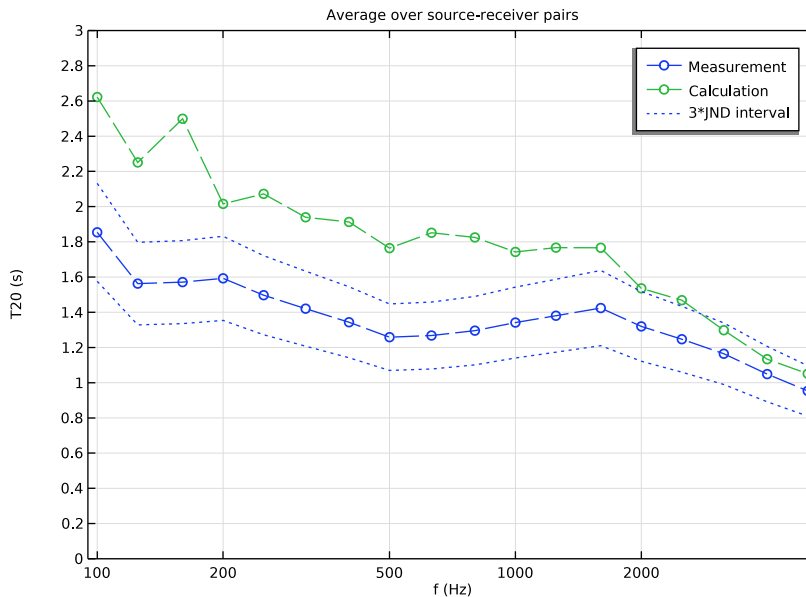
Expression	Unit	Description
$(1-3*0.05)*T20_meas(f0)$	s	

Global 3

- 1 In the **Model Builder** window, click **Global 3**.
- 2 In the **Settings** window for **Global**, locate the **y-Axis Data** section.
- 3 In the table, enter the following settings:

Expression	Unit	Description
$(1+3*0.05)*T20_meas(f0)$	s	

- 4 In the **Reverberation Time T20** toolbar, click  **Plot**.



Clarity C80

- 1 In the **Model Builder** window, right-click **Reverberation Time T20** and choose **Duplicate**.
- 2 In the **Settings** window for **ID Plot Group**, type Clarity C80 in the **Label** text field.

- 3 Locate the **Plot Settings** section. In the **y-axis label** text field, type C80 (dB).
- 4 Locate the **Axis** section. In the **y minimum** text field, type -5.
- 5 In the **y maximum** text field, type 8.
- 6 Locate the **Legend** section. From the **Position** list, choose **Upper left**.

Global 1

- 1 In the **Model Builder** window, expand the **Clarity C80** node, then click **Global 1**.
- 2 In the **Settings** window for **Global**, locate the **y-Axis Data** section.
- 3 In the table, enter the following settings:

Expression	Unit	Description
C80_meas (f0)	dB	Interpolation 11
$(C80_11(f0)+C80_12(f0)+C80_13(f0)+C80_14(f0)+C80_15(f0)+C80_21(f0)+C80_22(f0)+C80_23(f0)+C80_24(f0)+C80_25(f0))/10$	dB	

Global 2

- 1 In the **Model Builder** window, click **Global 2**.
- 2 In the **Settings** window for **Global**, locate the **y-Axis Data** section.
- 3 In the table, enter the following settings:

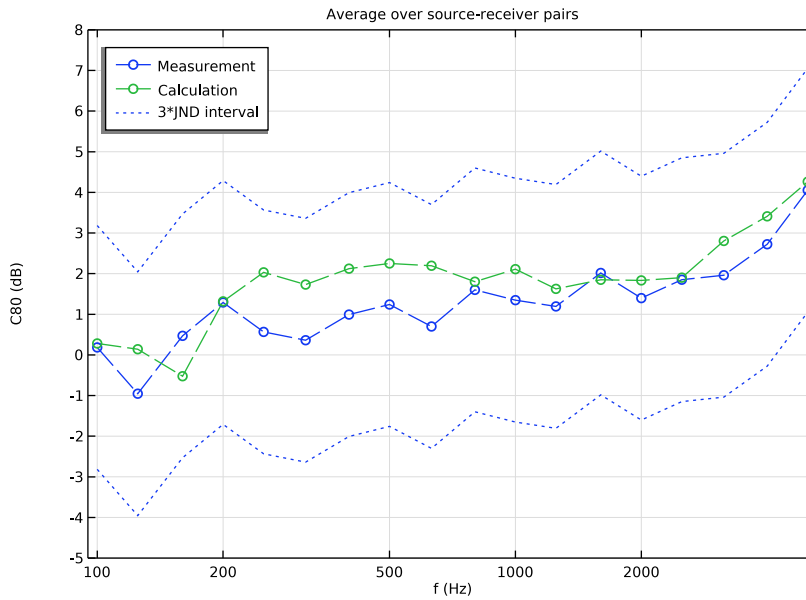
Expression	Unit	Description
C80_meas (f0) -3*1	dB	

Global 3

- 1 In the **Model Builder** window, click **Global 3**.
- 2 In the **Settings** window for **Global**, locate the **y-Axis Data** section.
- 3 In the table, enter the following settings:

Expression	Unit	Description
C80_meas (f0) +3*1	dB	

4 In the **Clarity C80** toolbar, click  **Plot**.



Definition D

- 1 In the **Model Builder** window, right-click **Clarity C80** and choose **Duplicate**.
- 2 In the **Settings** window for **ID Plot Group**, type Definition D in the **Label** text field.
- 3 Locate the **Plot Settings** section. In the **y-axis label** text field, type D (%).
- 4 Locate the **Axis** section. In the **y minimum** text field, type 0.
- 5 In the **y maximum** text field, type 100.

Global I

- 1 In the **Model Builder** window, expand the **Definition D** node, then click **Global I**.
- 2 In the **Settings** window for **Global**, locate the **y-Axis Data** section.
- 3 In the table, enter the following settings:

Expression	Unit	Description
D50_meas (f0)	%	Interpolation 12
100*(D50_11(f0)+D50_12(f0)+D50_13(f0)+D50_14(f0)+D50_15(f0)+D50_21(f0)+D50_22(f0)+D50_23(f0)+D50_24(f0)+D50_25(f0))/10		

Global 2


- 1 In the **Model Builder** window, click **Global 2**.
- 2 In the **Settings** window for **Global**, locate the **y-Axis Data** section.
- 3 In the table, enter the following settings:

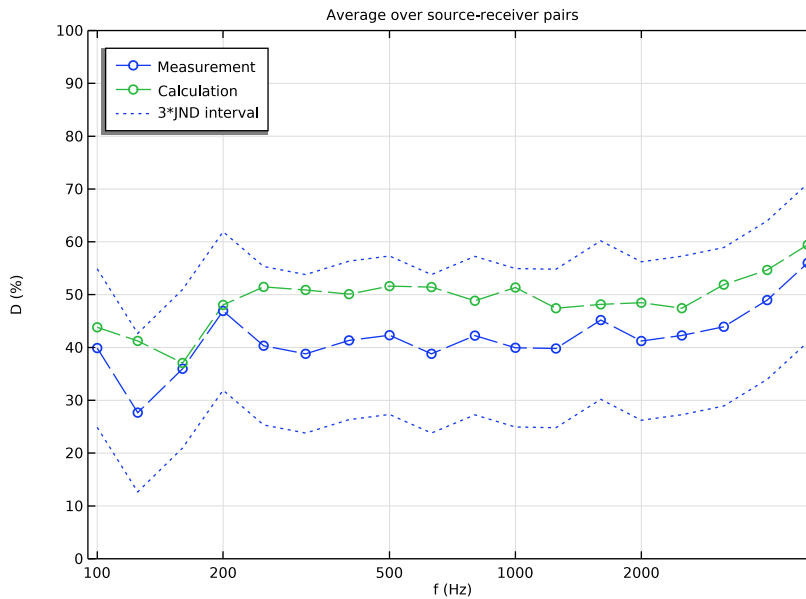
Expression	Unit	Description
$D50_meas(f_0) - 3 * 0.05$	%	

Global 3

- 1 In the **Model Builder** window, click **Global 3**.
- 2 In the **Settings** window for **Global**, locate the **y-Axis Data** section.
- 3 In the table, enter the following settings:

Expression	Unit	Description
$D50_meas(f_0) + 3 * 0.05$	%	

- 4 In the **Definition D** toolbar, click  **Plot**.




Geometry Modeling Instructions

The geometry in this model was provided by [Ref. 2](#). After importing it, the seating areas are extruded. The surfaces that have become obsolete are then deleted. Finally, surfaces are grouped into selections according to the assignment of materials.

From the **File** menu, choose **New**.

NEW





In the **New** window, click  **Blank Model**.

ADD COMPONENT


In the **Home** toolbar, click  **Add Component** and choose **3D**.

GEOMETRY 1

Import 1 (imp1)



- 1 In the **Geometry** toolbar, click  **Import**.
- 2 In the **Settings** window for **Import**, locate the **Source** section.
- 3 Click  **Browse**.
- 4 Browse to the model's Application Libraries folder and double-click the file `chamber_music_hall.mphbin`.
- 5 Click  **Import**.
- 6 Click the  **Wireframe Rendering** button in the **Graphics** toolbar.

Extrude 1 (ext1)

- 1 In the **Geometry** toolbar, click  **Extrude**.
- 2 On the object **imp1**, select Boundary 238 only.
- 3 In the **Settings** window for **Extrude**, locate the **Distances** section.
- 4 In the table, enter the following settings:

Distances (m)
0.8


Extrude 2 (ext2)

- 1 In the **Geometry** toolbar, click  **Extrude**.
- 2 Click the  **Go to Default View** button in the **Graphics** toolbar.
- 3 On the object **ext1**, select Boundaries 197, 213, 408, 419, and 661 only.

- 4 In the **Settings** window for **Extrude**, locate the **Distances** section.
- 5 In the table, enter the following settings:


Distances (m)
0.8

Extrude 3 (ext3)

- 1 In the **Geometry** toolbar, click  **Extrude**.
- 2 On the object **ext2**, select Boundary 724 only.
- 3 In the **Settings** window for **Extrude**, locate the **Distances** section.
- 4 In the table, enter the following settings:





Distances (m)
0.8




Extrude 4 (ext4)

- 1 In the **Geometry** toolbar, click  **Extrude**.
- 2 On the object **ext3**, select Boundary 746 only.
- 3 In the **Settings** window for **Extrude**, locate the **Distances** section.
- 4 In the table, enter the following settings:


Distances (m)
0.8

Delete Entities 1 (dell)



- 1 In the **Model Builder** window, right-click **Geometry 1** and choose **Delete Entities**.
- 2 Click the  **Go to Default View** button in the **Graphics** toolbar.
- 3 On the object **ext4**, select Boundaries 240, 252, 300, 359, 481, 543, and 597 only.
- 4 Click the  **Go to Default View** button in the **Graphics** toolbar.
- 5 On the object **ext4**, select Boundaries 228, 240, 252, 282, 300, 341, 359, 481, 543, and 597 only.
- 6 Click the  **Go to Default View** button in the **Graphics** toolbar.
- 7 On the object **ext4**, select Boundaries 228, 240, 252, 282, 300, 341, 359, 460, 481, 519, 543, 582, and 597 only.
- 8 Click the  **Go to Default View** button in the **Graphics** toolbar.

- 9 On the object **ext4**, select Boundaries 199, 220, 228, 240, 252, 282, 300, 341, 359, 436, 452, 460, 481, 519, 543, 582, and 597 only.
- 10 Click the  **Go to Default View** button in the **Graphics** toolbar.
- 11 On the object **ext4**, select Boundaries 199, 220, 228, 240, 252, 282, 300, 341, 359, 436, 452, 460, 481, 519, 543, 582, 597, 712, 714, 721, 723, 725, 742–744, 746, 750, 754, 755, and 760 only.
- 12 Click the  **Go to Default View** button in the **Graphics** toolbar.
- 13 On the object **ext4**, select Boundaries 199, 220, 228, 240, 252, 282, 300, 341, 359, 436, 452, 460, 481, 519, 543, 582, 597, 712, 714, 721, 723, 725, 742–746, 750, 751, 754, 755, and 760 only.
- 14 Click the  **Go to Default View** button in the **Graphics** toolbar.



All boundaries

- 1 In the **Geometry** toolbar, click  **Selections** and choose **Box Selection**.
- 2 In the **Settings** window for **Box Selection**, type All boundaries in the **Label** text field.
- 3 Locate the **Geometric Entity Level** section. From the **Level** list, choose **Boundary**.

Stage panels



- 1 In the **Geometry** toolbar, click  **Selections** and choose **Explicit Selection**.
- 2 In the **Settings** window for **Explicit Selection**, type Stage panels in the **Label** text field.
- 3 Click in the **Graphics** window and then press Ctrl+D to clear all objects.
- 4 Locate the **Entities to Select** section. From the **Geometric entity level** list, choose **Boundary**.
- 5 Click the  **Paste Selection** button for **Entities to select**.
- 6 In the **Paste Selection** dialog, type del1: 10, 11, 13-92 in the **Selection** text field.
- 7 Click **OK**.

Windows



- 1 In the **Geometry** toolbar, click  **Selections** and choose **Explicit Selection**.
- 2 In the **Settings** window for **Explicit Selection**, type Windows in the **Label** text field.
- 3 Click in the **Graphics** window and then press Ctrl+D to clear all objects.
- 4 Locate the **Entities to Select** section. From the **Geometric entity level** list, choose **Boundary**.
- 5 Click the  **Paste Selection** button for **Entities to select**.
- 6 In the **Paste Selection** dialog, type del1: 194, 369, 540, 725-728 in the **Selection** text field.

7 Click **OK**.


Seating


- 1 In the **Geometry** toolbar, click  **Selections** and choose **Explicit Selection**.
- 2 In the **Settings** window for **Explicit Selection**, type **Seating** in the **Label** text field.
- 3 Click in the **Graphics** window and then press **Ctrl+D** to clear all objects.
- 4 Locate the **Entities to Select** section. From the **Geometric entity level** list, choose **Boundary**.
- 5 Click the  **Paste Selection** button for **Entities to select**.
- 6 In the **Paste Selection** dialog, type del1: 158, 160, 162, 164, 166-169, 195, 197, 199, 200, 205, 209, 211, 222-224, 229, 231, 232, 246-249, 257, 263, 273-275, 280, 282-289, 309, 315, 319, 321, 330-332, 337, 339-346, 370, 376, 379, 381, 388, 411, 412, 414, 425, 427, 428, 445-447, 452, 454, 455, 459-464, 477, 482, 488, 492, 494, 502-504, 509, 511, 512, 516, 517, 521-524, 541, 547, 551, 553, 560, 561, 565, 570, 572, 573, 591, 597, 607, 608, 610, 613, 616, 618-621, 625-628, 635-638, 640-643, 681, 695-698, 703-705, 707, 714, 715, 717, 719-723 in the **Selection** text field.
- 7 Click **OK**.

Floor



- 1 In the **Geometry** toolbar, click  **Selections** and choose **Explicit Selection**.
- 2 In the **Settings** window for **Explicit Selection**, type **Floor** in the **Label** text field.
- 3 Click in the **Graphics** window and then press **Ctrl+D** to clear all objects.
- 4 Locate the **Entities to Select** section. From the **Geometric entity level** list, choose **Boundary**.
- 5 Click the  **Paste Selection** button for **Entities to select**.
- 6 In the **Paste Selection** dialog, type del1: 12, 96, 98-107, 109-115, 117, 119, 122, 126, 132, 135-140, 142, 146, 150, 154, 155, 184, 185, 188, 190, 193, 298, 300, 304, 363, 365, 368, 390, 393, 396, 397, 408, 413, 473, 475, 476, 534, 536, 539, 612, 617, 622, 624, 631, 632, 639, 659, 677, 684, 685, 699-702, 706, 712, 713, 716, 718, 730 in the **Selection** text field.
- 7 Click **OK**.

Ceiling


- 1 In the **Geometry** toolbar, click  **Selections** and choose **Explicit Selection**.
- 2 In the **Settings** window for **Explicit Selection**, type **Ceiling** in the **Label** text field.





- 3 Click in the **Graphics** window and then press Ctrl+D to clear all objects.
- 4 Locate the **Entities to Select** section. From the **Geometric entity level** list, choose **Boundary**.
- 5 Click the  **Paste Selection** button for **Entities to select**.
- 6 In the **Paste Selection** dialog, type del1: 2, 8, 97, 120, 127, 143, 152, 181, 186, 191, 238, 241, 250, 252, 295, 301, 305, 307, 352, 355, 359, 361, 366, 400, 403, 407, 415, 417, 456, 470, 478, 480, 513, 518, 530, 532, 537, 562, 574, 584, 586, 646, 647, 649, 650, 652, 653, 655, 656, 663, 690, 693, 709 in the **Selection** text field.
- 7 Click **OK**.

Structured plaster

- 1 In the **Geometry** toolbar, click  **Selections** and choose **Explicit Selection**.
- 2 In the **Settings** window for **Explicit Selection**, type Structured plaster in the **Label** text field.
- 3 Click in the **Graphics** window and then press Ctrl+D to clear all objects.
- 4 Locate the **Entities to Select** section. From the **Geometric entity level** list, choose **Boundary**.
- 5 Click the  **Paste Selection** button for **Entities to select**.
- 6 In the **Paste Selection** dialog, type del1: 1, 3-7, 9, 108, 121, 128-131, 145, 148, 149, 151, 153, 171-180, 182, 187, 198, 201-204, 206, 208, 212-216, 218, 220, 225, 227, 233, 235, 239, 243, 251, 253, 259-262, 264, 266-272, 276, 278, 290, 292, 296, 303, 306, 308, 311-314, 316, 318, 323, 324, 326-329, 333, 335, 347, 349, 353, 357, 358, 360, 362, 372-375, 377, 378, 382-387, 389, 391, 392, 394, 395, 399, 401, 405, 416, 418, 426, 429-439, 441, 443, 448, 450, 457, 465, 467, 472, 479, 481, 484-487, 489, 491, 496-501, 505, 507, 514, 520, 525, 527, 531, 533, 543-546, 548, 550, 554-559, 563, 566, 568, 576, 577, 579, 585, 587, 593-596, 598, 600-606, 611, 614, 615, 629, 630, 634, 680, 711 in the **Selection** text field.
- 7 Click **OK**.

Plaster

- 1 In the **Geometry** toolbar, click  **Selections** and choose **Difference Selection**.
- 2 In the **Settings** window for **Difference Selection**, type Plaster in the **Label** text field.
- 3 Locate the **Geometric Entity Level** section. From the **Level** list, choose **Boundary**.

- 4 Locate the **Input Entities** section. Click the  **Add** button for **Selections to add**.
- 5 In the **Add** dialog, select **All boundaries** in the **Selections to add** list.
- 6 Click **OK**.
- 7 In the **Settings** window for **Difference Selection**, locate the **Input Entities** section.
- 8 Click the  **Add** button for **Selections to subtract**.
- 9 In the **Add** dialog, in the **Selections to subtract** list, choose **Stage panels, Windows, Seating, Floor, Ceiling**, and **Structured plaster**.
- 10 Click **OK**.
- 11 In the **Geometry** toolbar, click  **Build All**.
- 12 Click the  **Go to Default View** button in the **Graphics** toolbar.