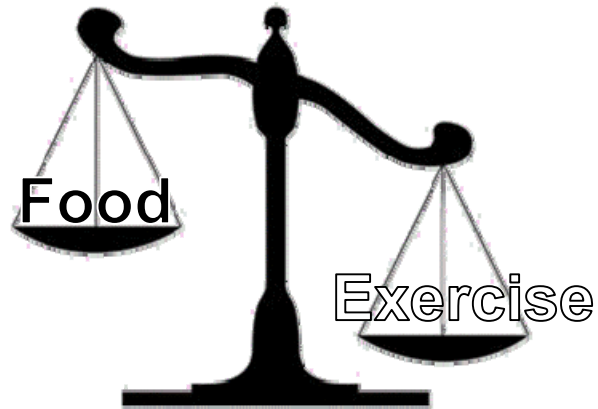


A simulation test bench for decay times in room acoustics

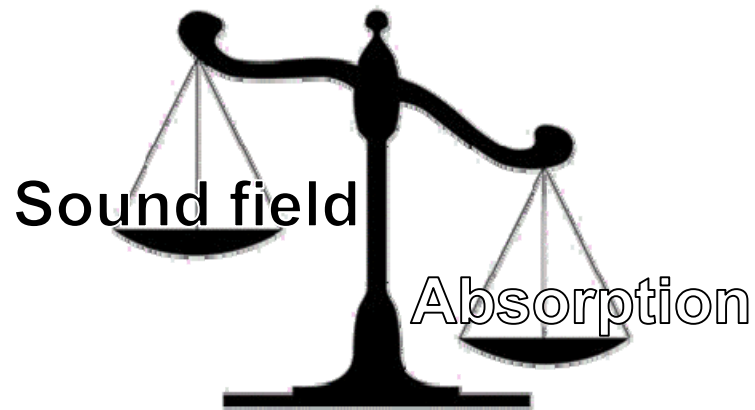
R. Magalotti, V. Cardinali

OLD

CALORIES

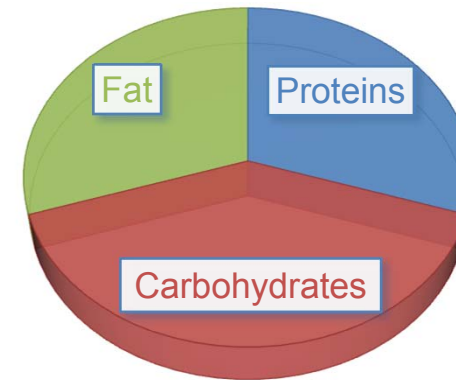


REVERBERATION



NEW

NUTRIENTS

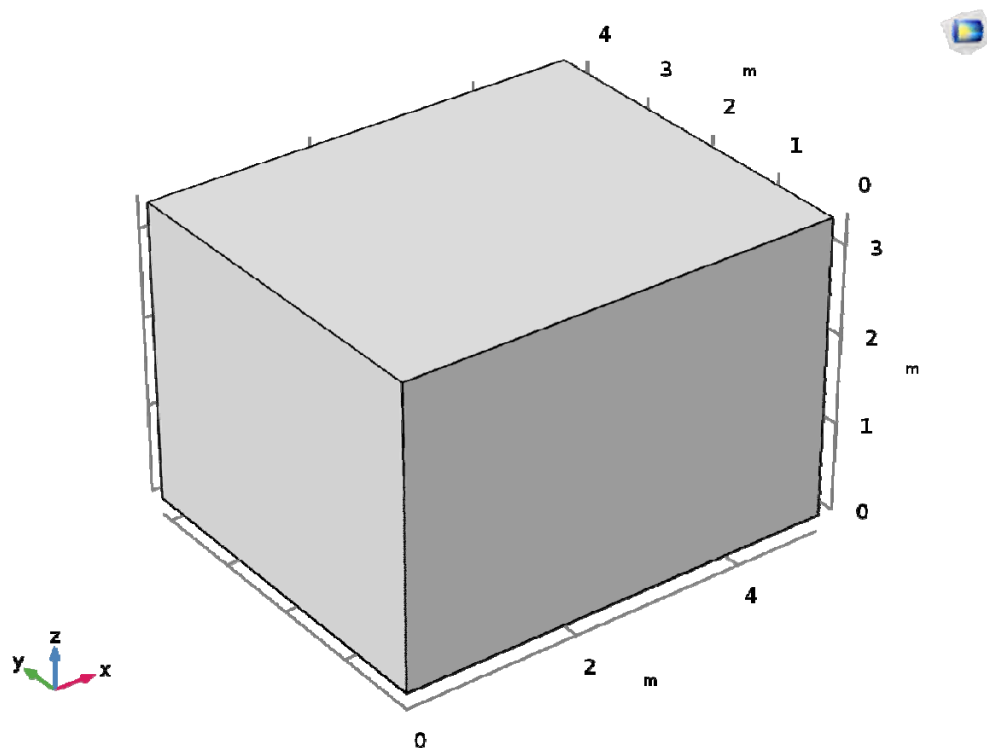


NORMAL MODES

- Shape
- Frequency
- Decay time

Rectangular room

- Size: 70 m³
5.02 × 4.15 × 3.36 m



- Modes below 100 Hz:

Mode	Frequency (Hz)
[1,0,0]	34.2
[0,1,0]	41.4
[0,0,1]	51.1
[1,1,0]	53.7
[1,0,1]	61.5
[0,1,1]	65.7
[2,0,0]	68.4
[1,1,1]	74.1
[2,1,0]	79.9
[0,2,0]	82.7
[2,0,1]	85.3
[1,2,0]	89.5
[2,1,1]	94.8
[0,2,1]	97.2

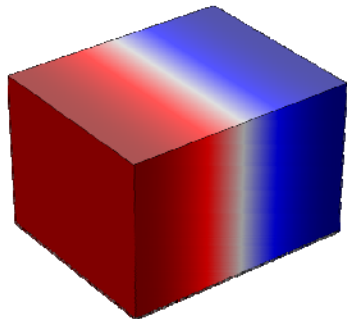
Mode classification

Axial

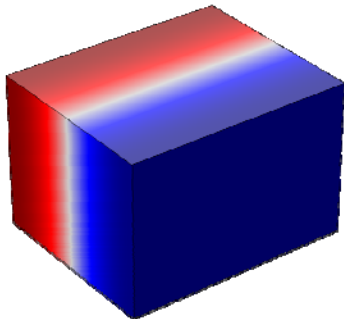
Tangential

Oblique

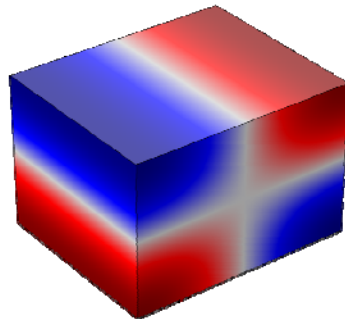
[1,0,0] Eigenfrequency=34.183 Hz



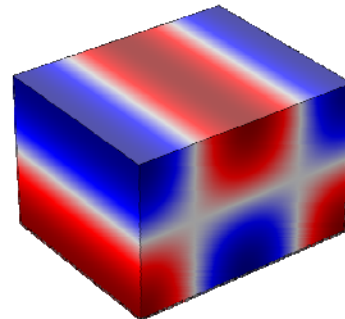
[0,1,0] Eigenfrequency=41.35 Hz



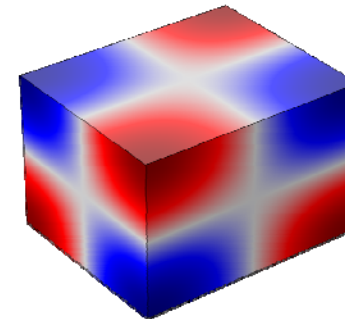
[1,0,1] Eigenfrequency=61.456 Hz



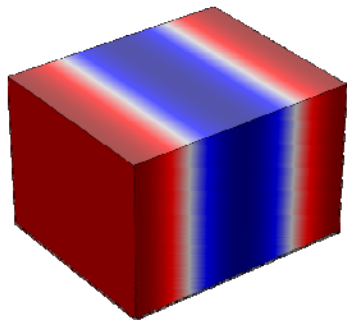
[2,0,1] Eigenfrequency=85.337 Hz



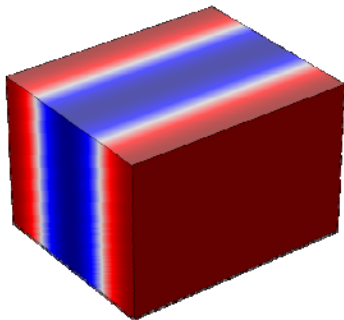
[1,1,1] Eigenfrequency=74.072 Hz



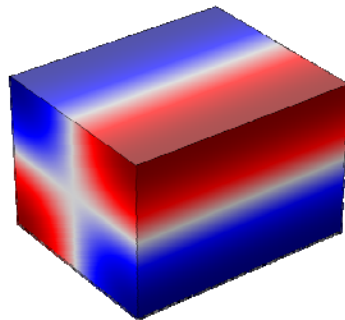
[2,0,0] Eigenfrequency=68.368 Hz



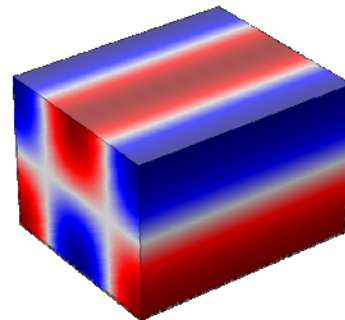
[0,2,0] Eigenfrequency=82.701 Hz



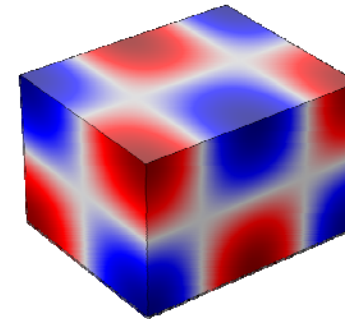
[0,1,1] Eigenfrequency=65.713 Hz



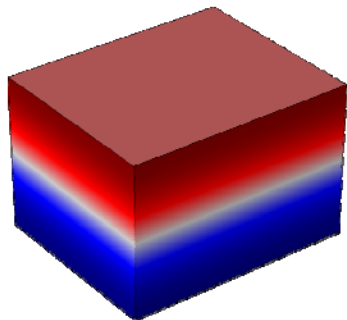
[0,2,1] Eigenfrequency=97.2 Hz



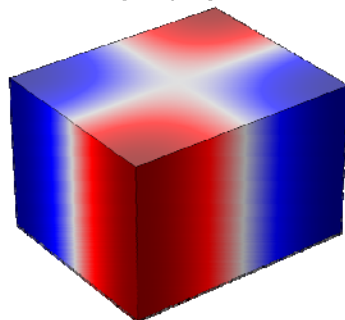
[2,1,1] Eigenfrequency=94.828 Hz



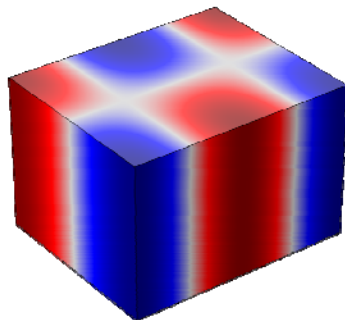
[0,0,1] Eigenfrequency=51.072 Hz



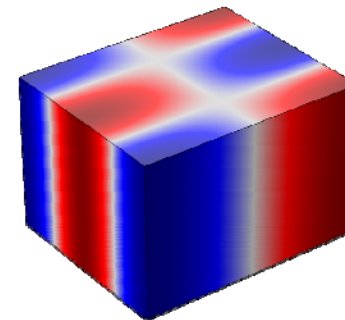
[1,1,0] Eigenfrequency=53.65 Hz



[2,1,0] Eigenfrequency=79.9 Hz

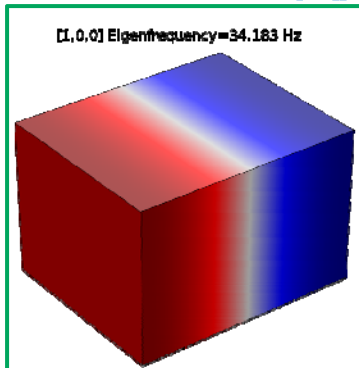


[1,2,0] Eigenfrequency=69.487 Hz

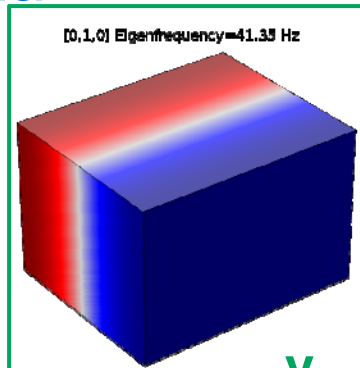
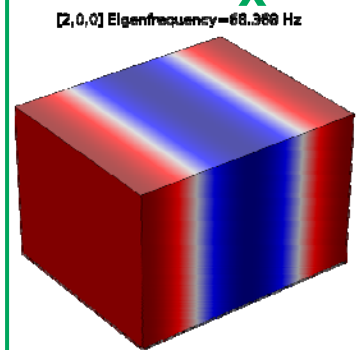


Mode classification

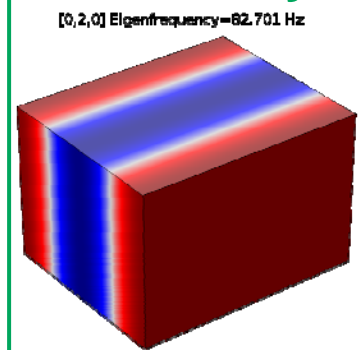
Axial



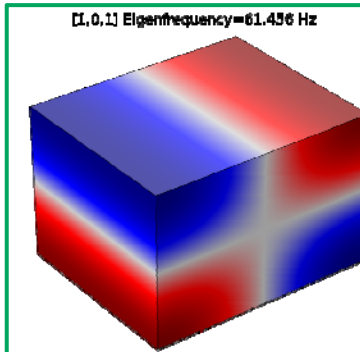
x



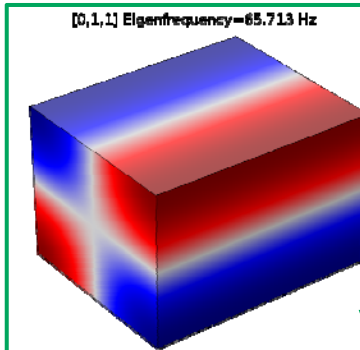
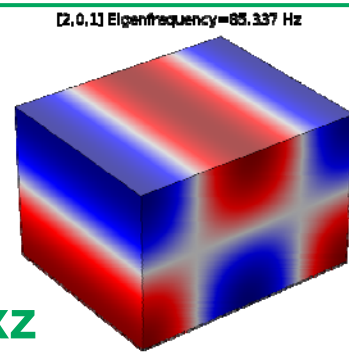
y



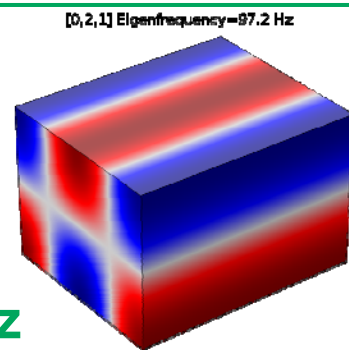
Tangential



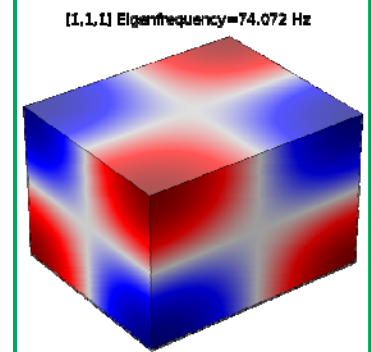
xz



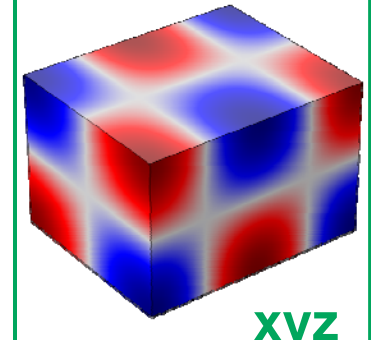
yz



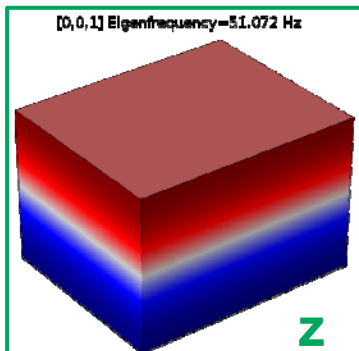
Oblique



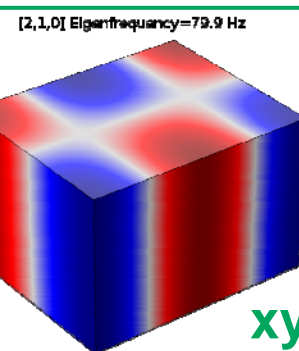
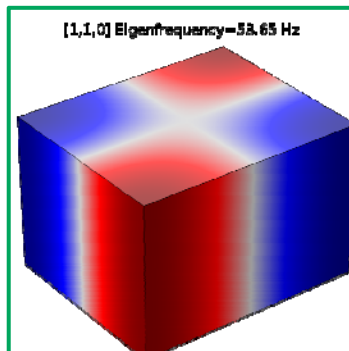
[2,1,1] Eigenfrequency=94.828 Hz



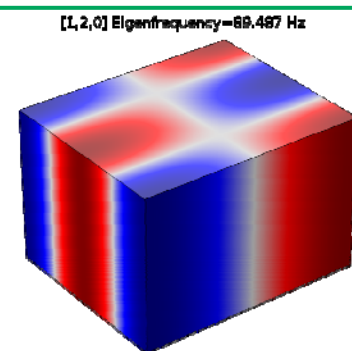
xyz



z



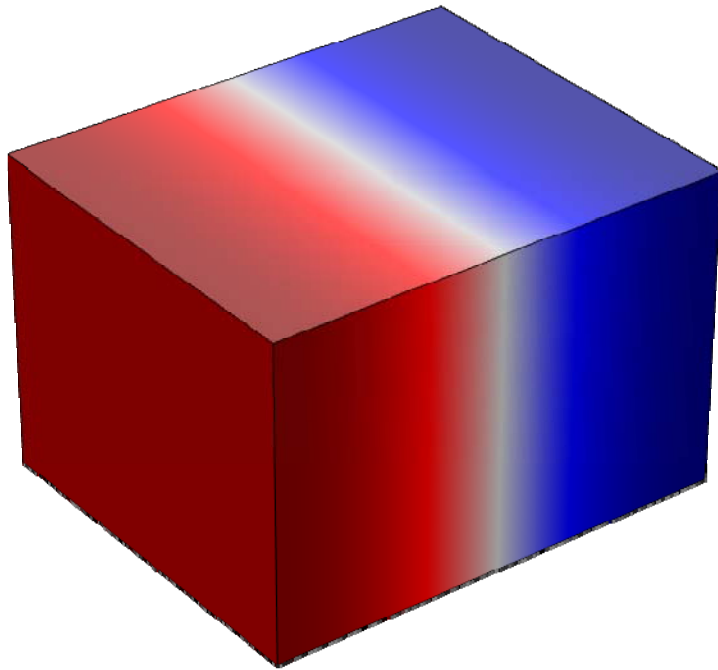
xy



Modal decay times in COMSOL

Sound Hard Walls

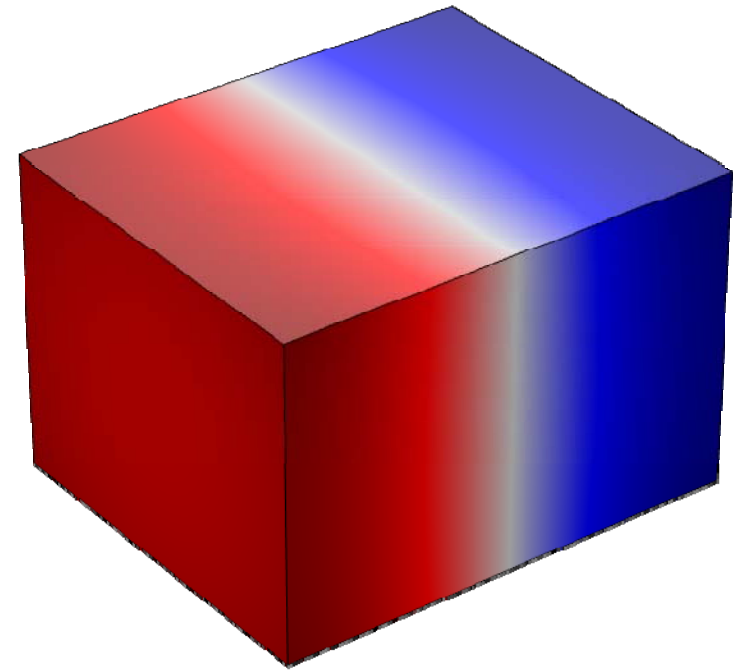
[1,0,0] Eigenfrequency=34.183 Hz



$$MT_{60} = \frac{1.1}{\text{imag}(freq)}$$

Finite Walls Impedance

[1,0,0] Eigenfrequency=34.182+0.36569i Hz



$$\Rightarrow MT_{60} = \frac{1.1}{0.366[\text{Hz}]} = 3[\text{s}]$$

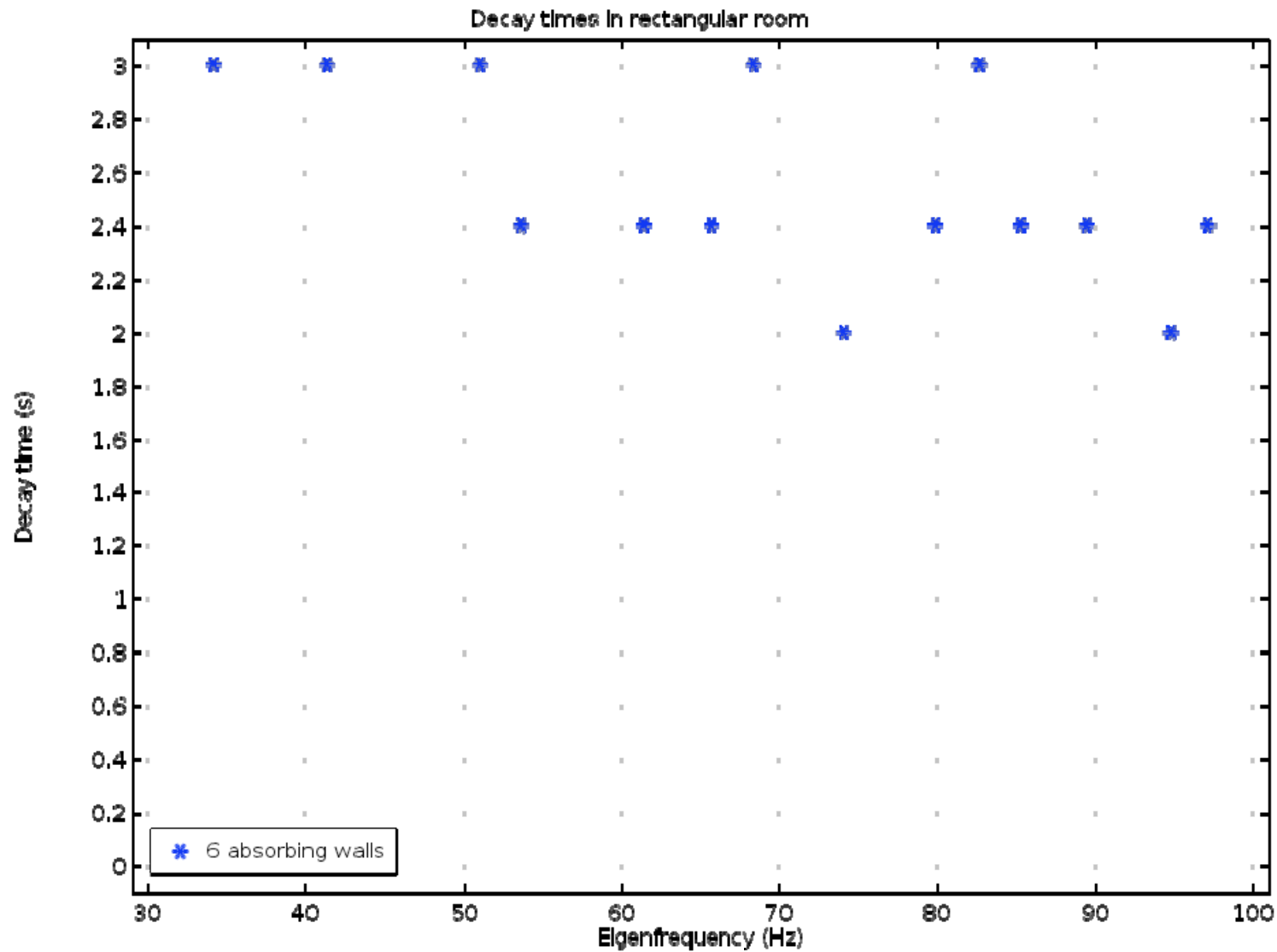
Wall impedance $\leftrightarrow MT_{60}$

Formula to get the same MT_{60} in all **axial** modes:

$$\zeta_i = \frac{Z_i}{\rho c} \approx 200 \frac{MT_{60}}{l_i}$$

The screenshot displays the COMSOL Multiphysics software interface. On the left, the Model Builder tree shows the hierarchy of the model, including Global Definitions, Component 1 (comp1), and Pressure Acoustics, Frequency Domain (acpr). The right wall is highlighted in purple. The Graphics window shows a 3D view of the rectangular room with dimensions 4m x 4m x 3m. The Settings window shows the Impedance model set to 'User defined' with the equation $Z_i = 1.2[\text{kg}/\text{m}^3] \cdot 343[\text{m}/\text{s}] \cdot 200[\text{m}/\text{s}] \cdot \text{MT60}/L1$.

Rectangular room decay times



Single absorbing wall

The screenshot displays the COMSOL Multiphysics software interface for a 3D acoustic model of a rectangular room. The room is defined by a grid with dimensions of 4m by 4m by 3m. A single wall on the left side is highlighted in blue, representing an absorbing boundary. The Selection List on the left shows the model hierarchy, with the 'Impedance x1' property selected under the 'Sound Hard Boundary (Wall) 1' component. The Settings window at the bottom right shows the configuration for the 'Impedance' property, including temperature (293.15 K), absolute pressure (1 atm), and the impedance model (User defined). The impedance is defined as $Z_i = 1.2[\text{kg}/\text{m}^3] * 343[\text{m}/\text{s}] * 200[\text{m}/\text{s}] * \text{MT60}/\text{L1}$.

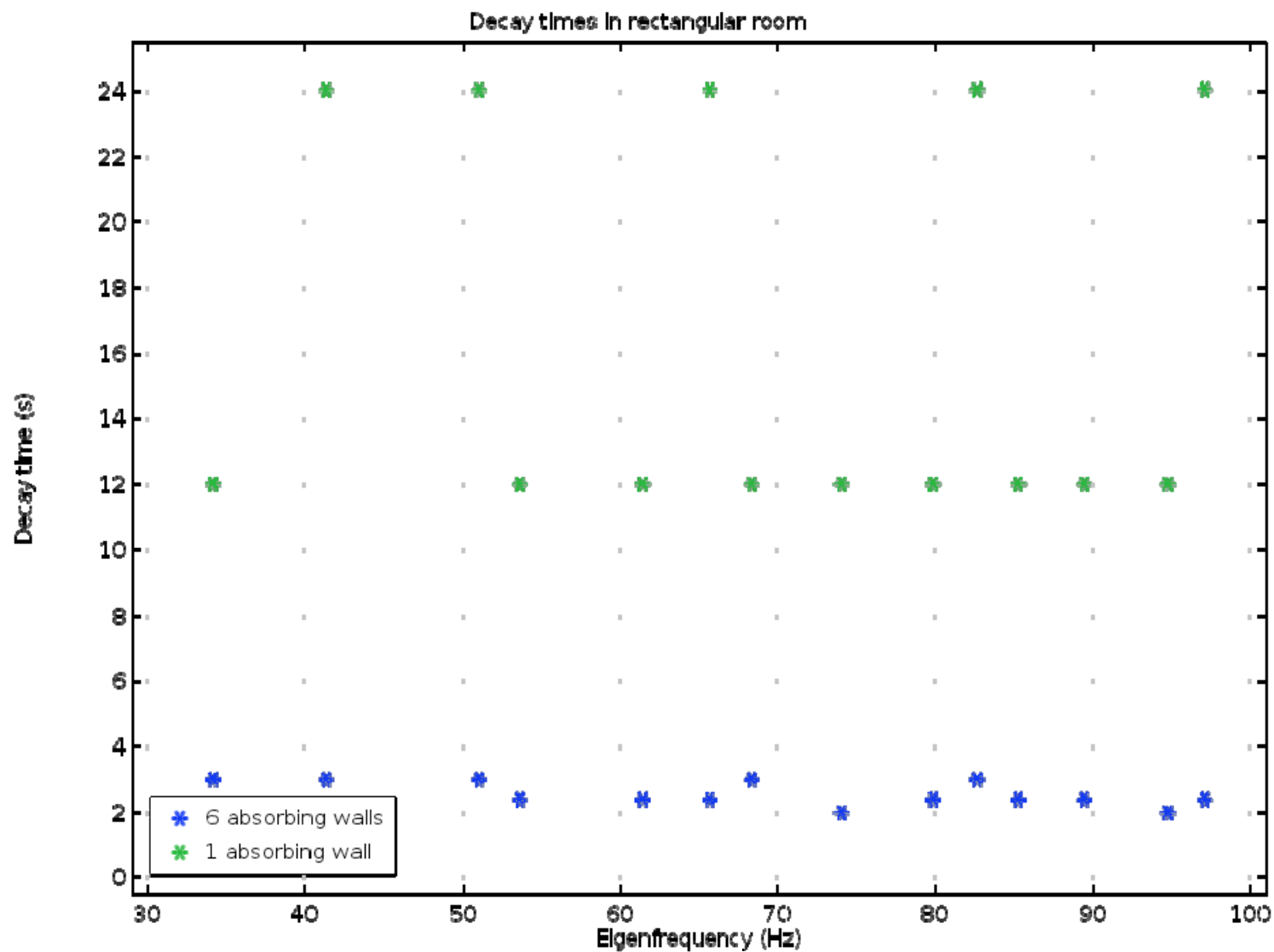
Selection List

- 2018-07-11 camera rettangolare MT60 3 secondi.mph (root)
 - Global Definitions
 - Parameters
 - Materials
 - Component 1 (comp1) (comp1)
 - Definitions
 - Geometry 1 (geom1)
 - Materials
 - Pressure Acoustics, Frequency Domain (acpr) (acpr)
 - Pressure Acoustics 1 (fpam1)
 - Sound Hard Boundary (Wall) 1 (shb1)
 - Initial Values 1 (init1)
 - Impedance x1 (imp1)**
 - Impedance x2 (imp4)
 - Impedance y1 (imp2)
 - Impedance y2 (imp5)
 - Impedance z1 (imp3)
 - Impedance z2 (imp6)
 - Impedance uniform (imp7)
 - Equation View (info)
 - Mesh 1 (mesh1)
 - Study 1 (std1)
 - Results
 - Data Sets
 - Derived Values
 - Tables
 - Table 1 (tbl1)
 - Acoustic Pressure (acpr) (pg1)
 - Sound Pressure Level (acpr) (pg2)
 - Acoustic Pressure, Isosurfaces (acpr) (pg3)
 - MT60 (pg4)
 - Table Graph 1 (tblp1)
 - Export
 - Reports

Single absorbing wall

- Expectations
 - Decay time of axial modes in x will double
 - Decay time of all other modes will be even higher, because of reduced absorption from the x wall

Single absorbing wall: decay times



Single absorbing wall

- Expectations

- Decay time of axial modes in x will double
- Decay time of all other modes will be even higher, because of reduced absorption on the x wall

- Results

- Decay time of axial modes in x is **4x**
- Many modes have the same decay time as the axial modes in x
- Only the modes with $[0,n,m]$ mode index have a higher decay time

Conclusions

- Simple relationships between modal decay times and wall impedances can be found and tested
- Therefore, the acoustic impedance of real walls can be computed from measurements of modal decay times
- In the case shown, lateral walls account for **half** the absorption of axial modes
- FEM simulations are very helpful in investigating models of low frequency room acoustics

THIS IS JUST THE BEGINNING

Thank you!

Roberto Magalotti
rmagalotti@bcspeakers.com



Theoretical Acoustics, pag. 572

$$q_{x0} \simeq \frac{1}{\pi i} \sqrt{ikl_x(\beta_{x0} + \beta_{x1})} \quad q_{xn} \simeq n - i \frac{kl_x}{\pi^2 n} (\beta_{x0} + \beta_{x1})$$

$$K_n^2 \simeq \left(\frac{\pi q_{xn_x}}{l_x} \right)^2 + \left(\frac{\pi q_{yn_y}}{l_y} \right)^2 + \left(\frac{\pi q_{zn_z}}{l_z} \right)^2$$

$$K_n \simeq \eta_n - \frac{ik}{2\eta_n} \left(\epsilon_{n_x} \frac{\beta_{x0} + \beta_{x1}}{l_x} + \epsilon_{n_y} \frac{\beta_{y0} + \beta_{y1}}{l_y} + \epsilon_{n_z} \frac{\beta_{z0} + \beta_{z1}}{l_z} \right) \quad (9.4.31)$$

$$\Psi_n \simeq \cos \left(q_{xn_x} \frac{\pi x}{l_x} + i\beta_{x0} \frac{kl_x}{\pi q_{xn_x}} \right) \\ \times \cos \left(q_{yn_y} \frac{\pi y}{l_y} + i\beta_{y0} \frac{kl_y}{\pi q_{yn_y}} \right) \cos \left(q_{zn_z} \frac{\pi z}{l_z} + i\beta_{z0} \frac{kl_z}{\pi q_{zn_z}} \right)$$