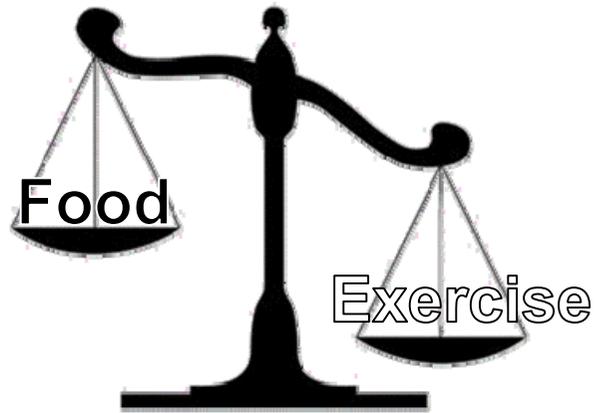


# A simulation test bench for decay times in room acoustics

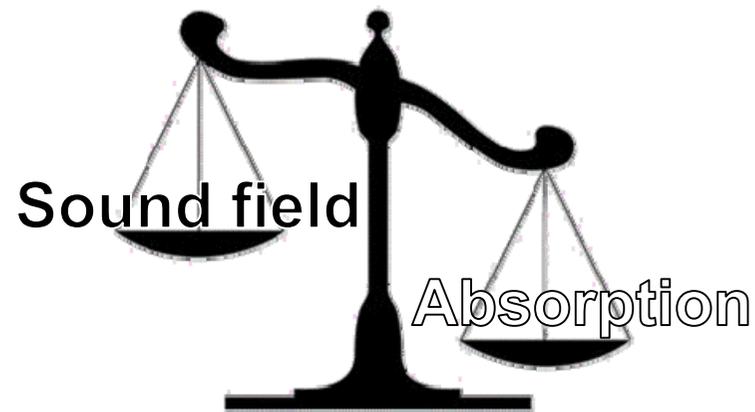
R. Magalotti, V. Cardinali

# OLD

## CALORIES

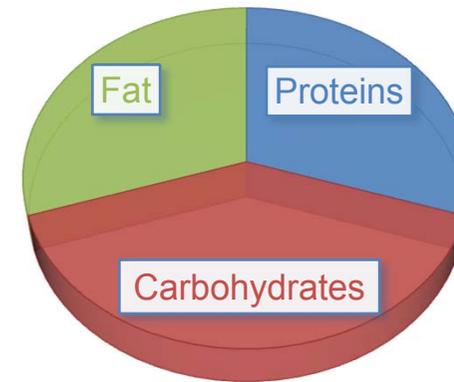


## REVERBERATION



# NEW

## NUTRIENTS

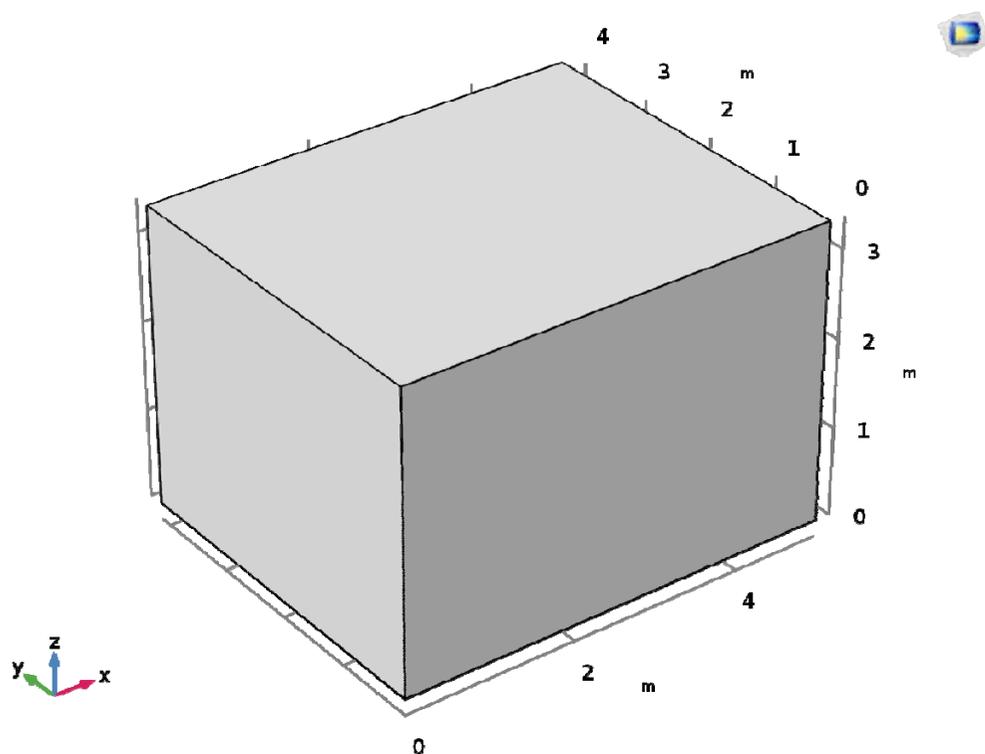


## NORMAL MODES

- Shape
- Frequency
- Decay time

# Rectangular room

- Size:  $70 \text{ m}^3$   
 $5.02 \times 4.15 \times 3.36 \text{ m}$



- 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           |

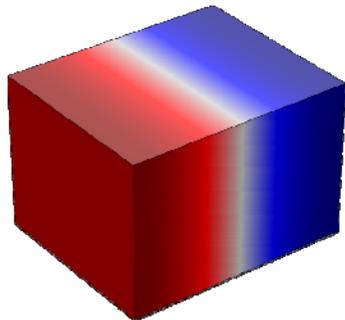
# Mode classification

## Axial

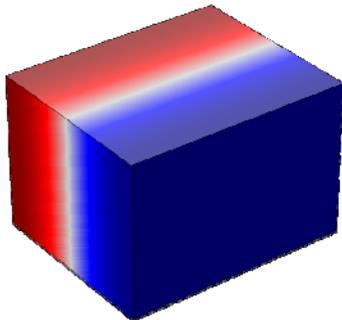
## Tangential

## Oblique

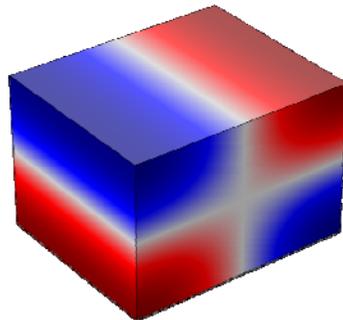
[1,0,0] Eigenfrequency=34.183 Hz



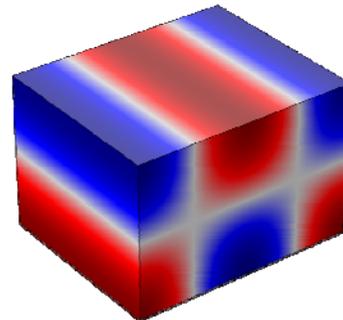
[0,1,0] Eigenfrequency=41.35 Hz



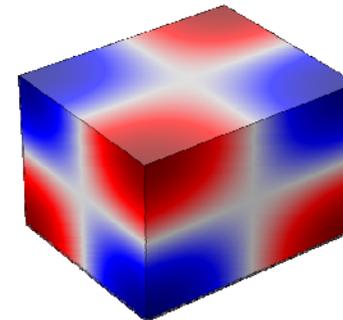
[1,0,1] Eigenfrequency=61.456 Hz



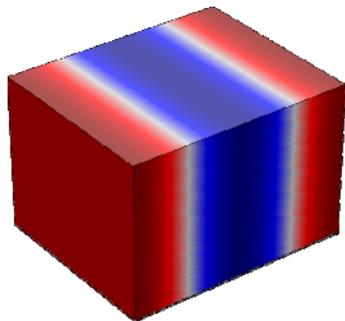
[2,0,1] Eigenfrequency=85.337 Hz



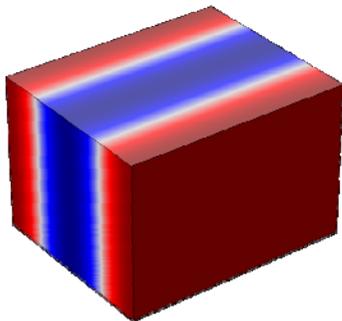
[1,1,1] Eigenfrequency=74.072 Hz



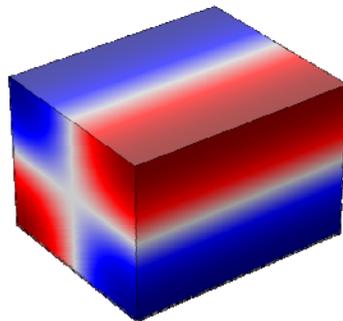
[2,0,0] Eigenfrequency=68.368 Hz



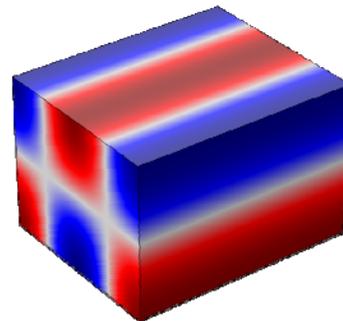
[0,2,0] Eigenfrequency=82.701 Hz



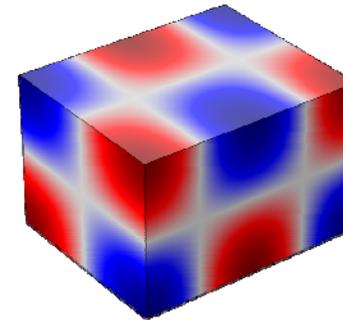
[0,1,1] Eigenfrequency=65.713 Hz



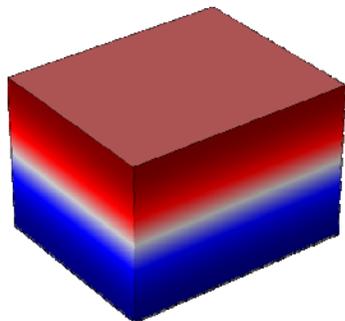
[0,2,1] Eigenfrequency=97.2 Hz



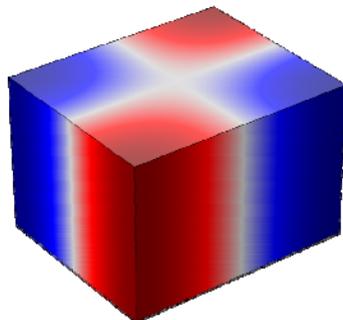
[2,1,1] Eigenfrequency=94.828 Hz



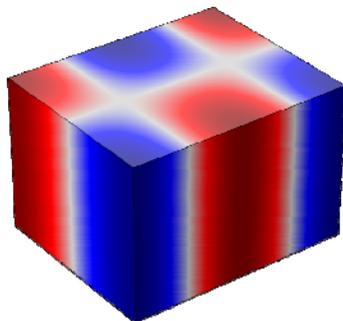
[0,0,1] Eigenfrequency=51.072 Hz



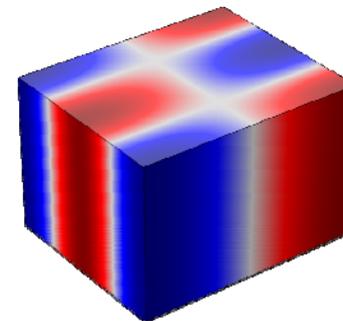
[1,1,0] Eigenfrequency=58.65 Hz



[2,1,0] Eigenfrequency=79.9 Hz

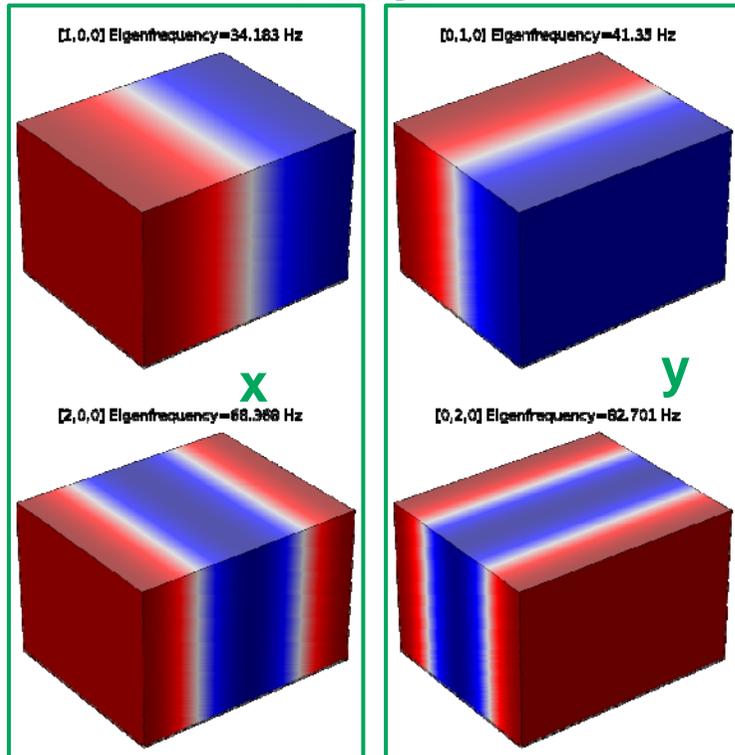


[1,2,0] Eigenfrequency=69.487 Hz

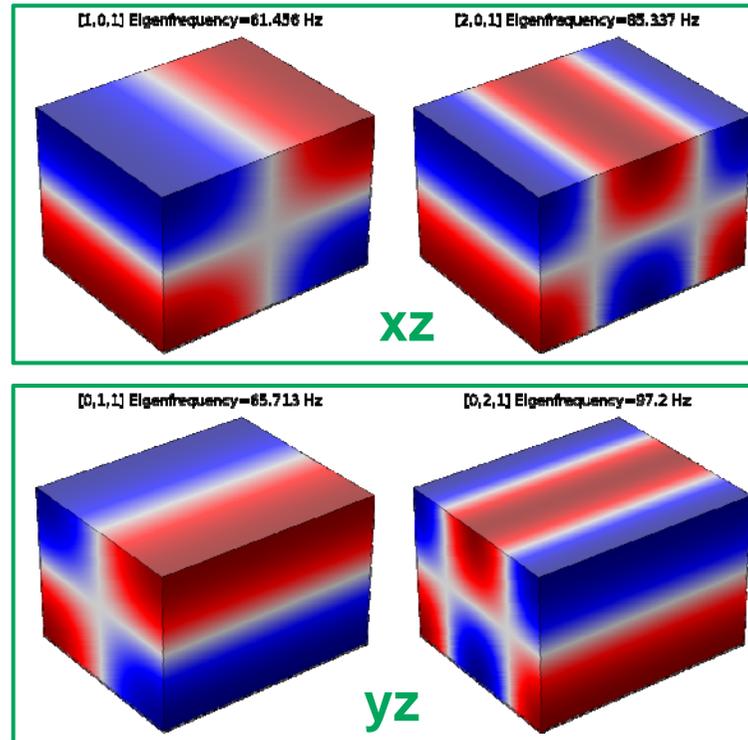


# Mode classification

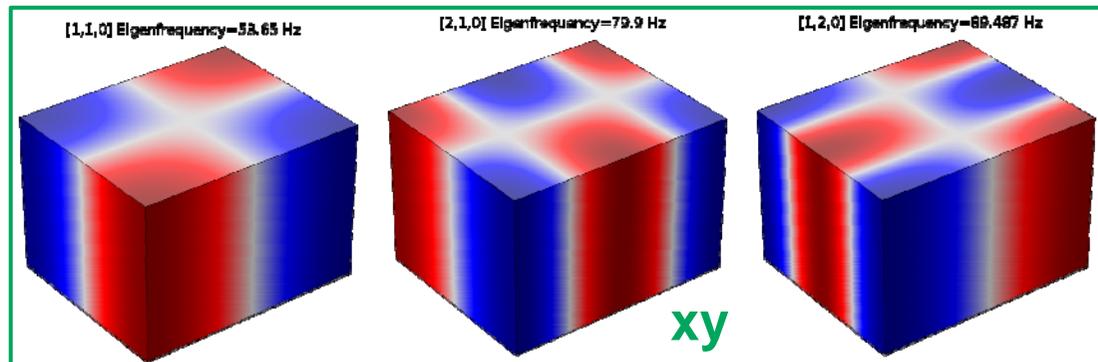
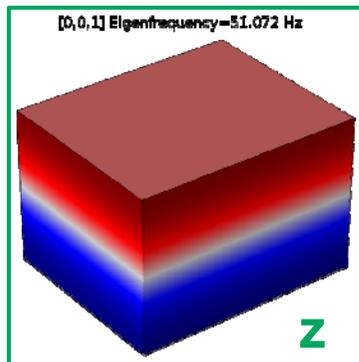
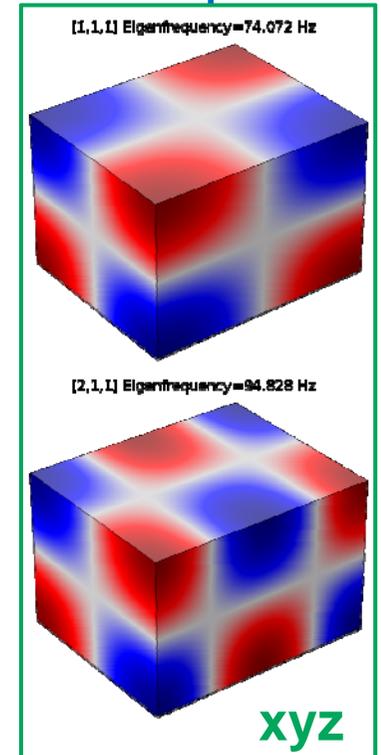
## Axial



## Tangential



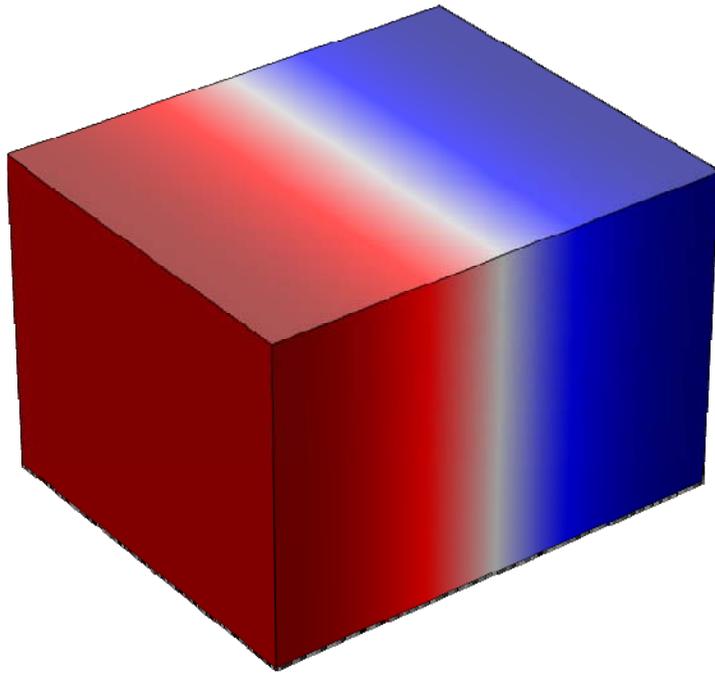
## Oblique



# Modal decay times in COMSOL

## Sound Hard Walls

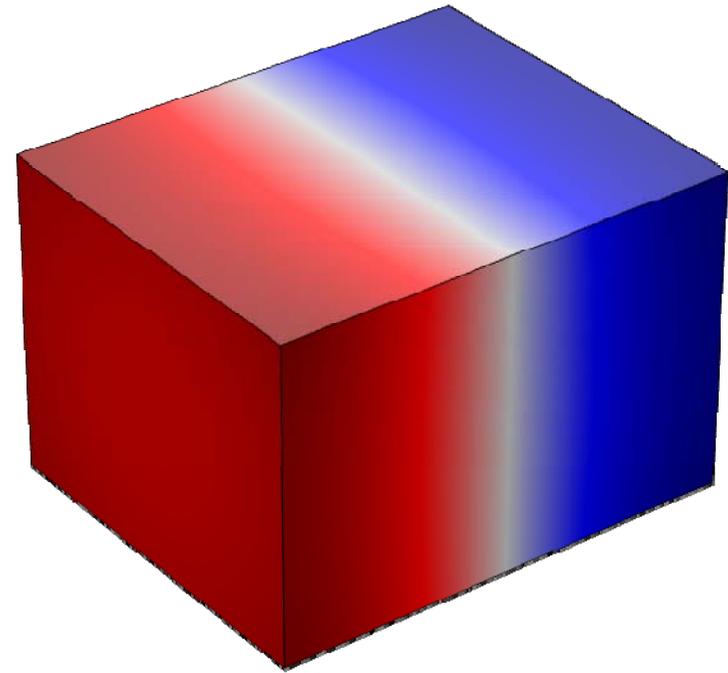
[1,0,0] Eigenfrequency=34.183 Hz



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

## Finite Walls Impedance

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



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

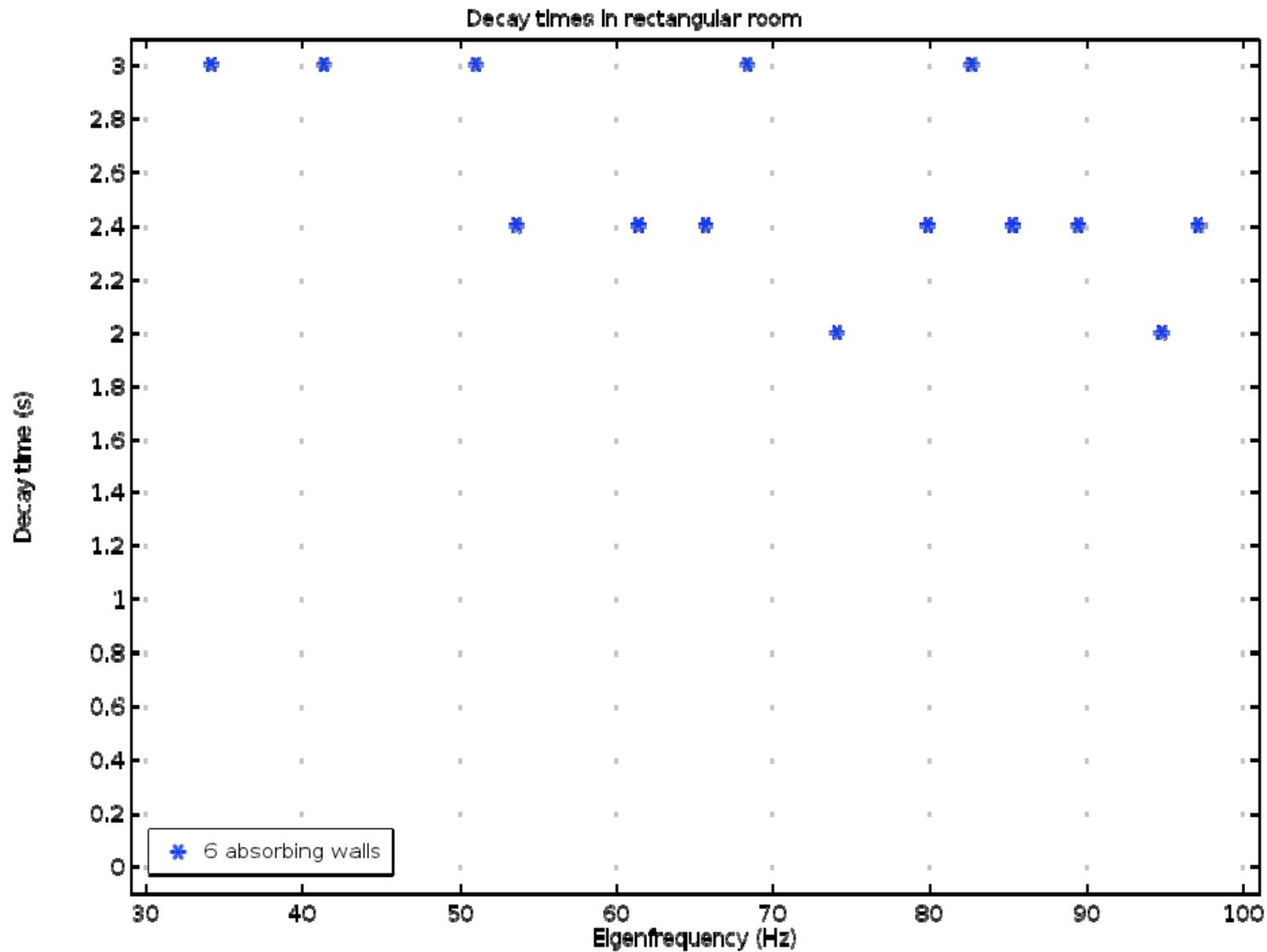
# Wall impedance $\leftrightarrow MT_{60}$

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 side of the interface is divided into two main sections: Graphics and Settings. The Graphics window shows a 3D wireframe model of a rectangular room with dimensions 4m x 4m x 3m. The left wall is highlighted in purple. 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. The Settings window at the bottom right shows the configuration for the 'Impedance' property, including temperature, absolute pressure, and the impedance model.

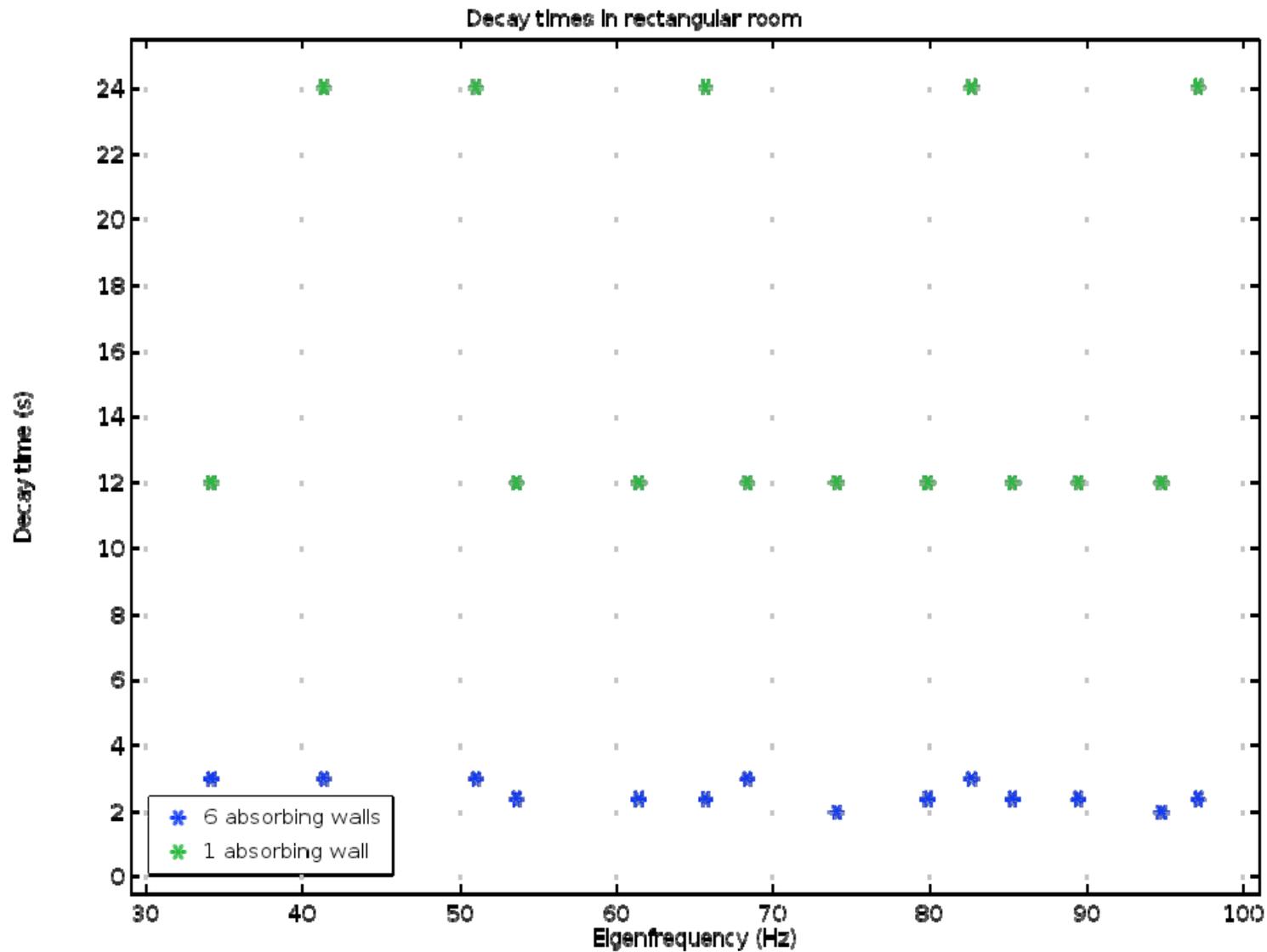
**Selection List:**

- 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

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# Theoretical Acoustics, pag. 572

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

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

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

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