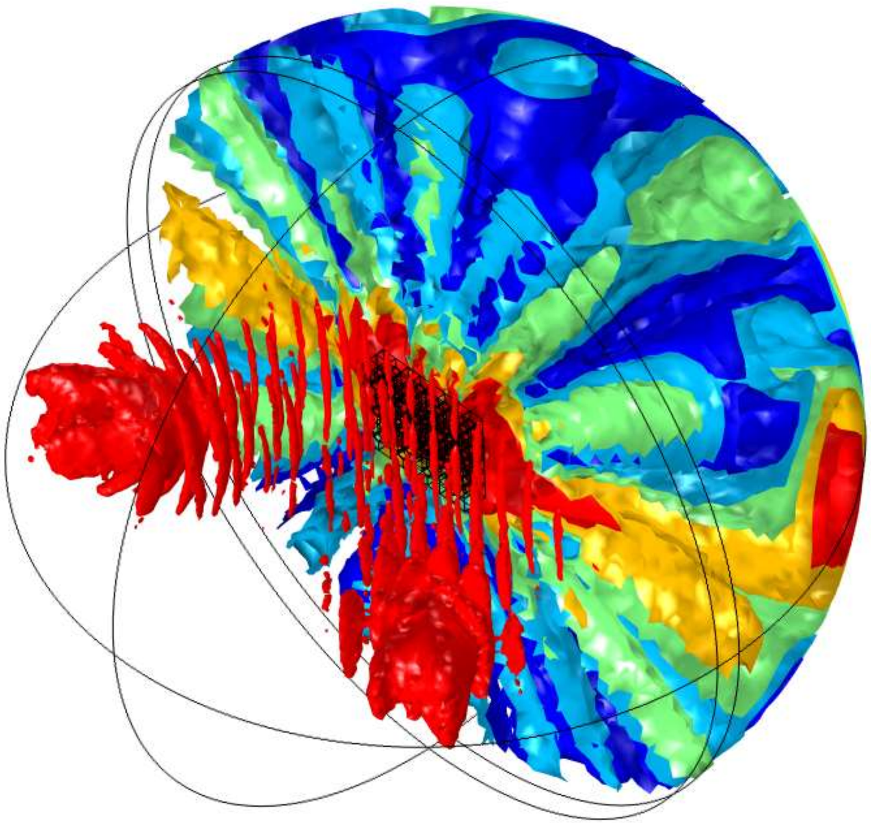
Analysis of an Air Transparent Soundproof Window System & Comparison to Physical Test Data



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Introduction

Image courtesy: www.bitrebels.com

- Sound, unlike light, is a longitudinal wave and therefore requires medium to propagate through.
- Sound is infused with its medium through pressure.
- Architects and designers are looking for new novel ways to provide ventilation for buildings which requires less space and energy.
- One such system is an air transparent soundproof window as discussed by Kim & Lee [1] in their paper.
- COMSOL Multiphysics was used to model such a system which not only attenuated sound but also allowed free flow of air.

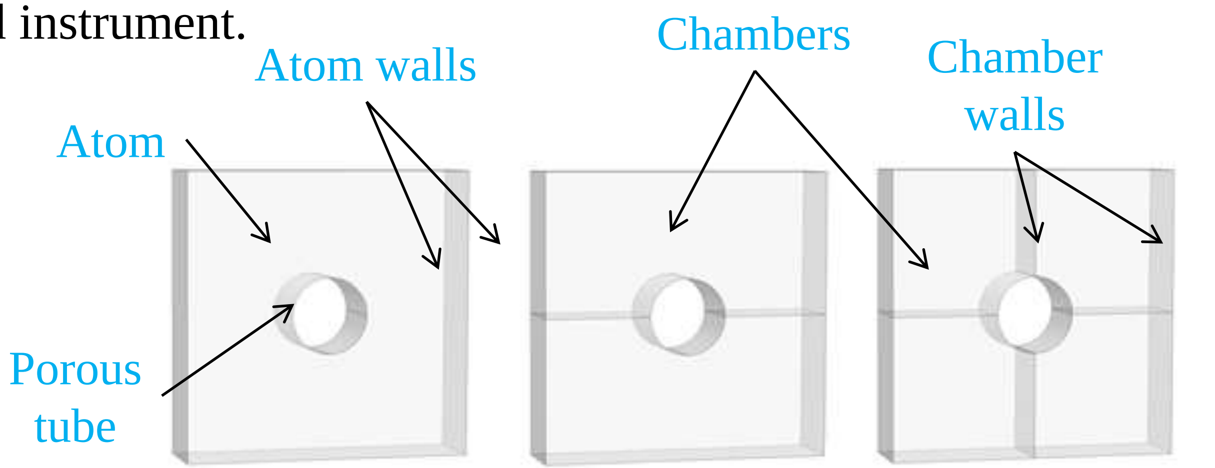
Conditions for Sound Isolation

Image courtesy: Wikipedia

- There are two important conditions for developing a soundproof window system free air flow.
- The first condition is to create strong sound diffraction.
  - Achieved by using diffraction resonators which replicates a modified Helmholtz resonator.
- The second condition is to achieve a negative bulk modulus of the resonators.

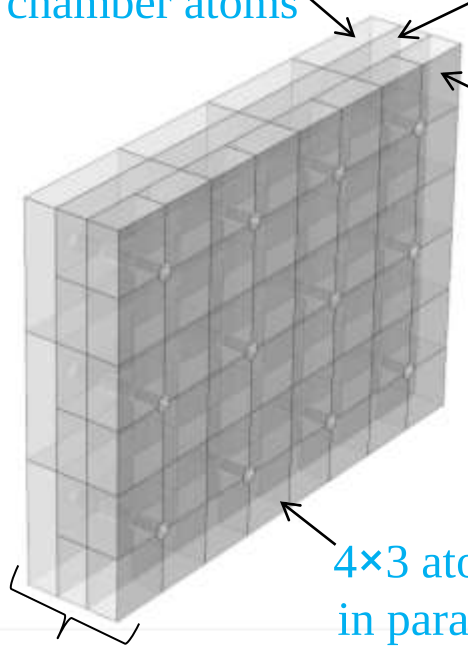
Design of the Window System

- The window system is composed of several sub-structures called atoms (or cells).
- Dimension of each cell is 150 mm x150 mm x 40 mm.
- Three variations of atoms are present:
  1. Atom with one resonating chamber
  2. Atom with two resonating chambers
  3. Atom with four resonating chambers
- Each chamber has an air hole in the centre to allow free flow of air.
- Air hole and the adjacent resonators are separated by porous filter.
  - The filter reduces the noise and prevents the resonators for acting like a wind instrument.



1) One Chamber 2) Two Chamber 3) Four Chamber

Design of the Window System



- Each atom is then placed in series and parallel to form a complete window system.
- The window is made of transparent acrylic plastic of 5 mm thickness.
- For strong diffraction of sound, the diameter of air hole must be smaller than the wavelength of sound wave applied.

$$f < f_D \quad [1]$$

- Keeping this in mind, two air hole sizes were selected for simulation:
  - Ø 20 mm (A-type)
  - Ø 50 mm (B-type)

Physical Tests on Window System

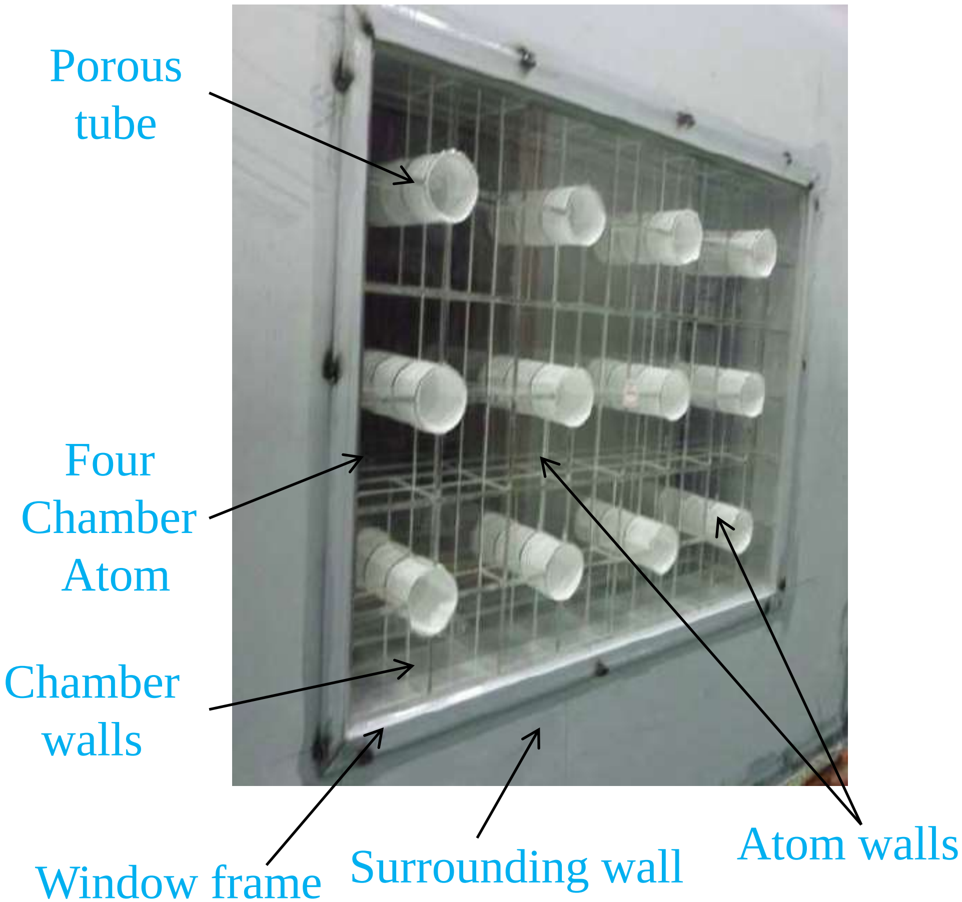
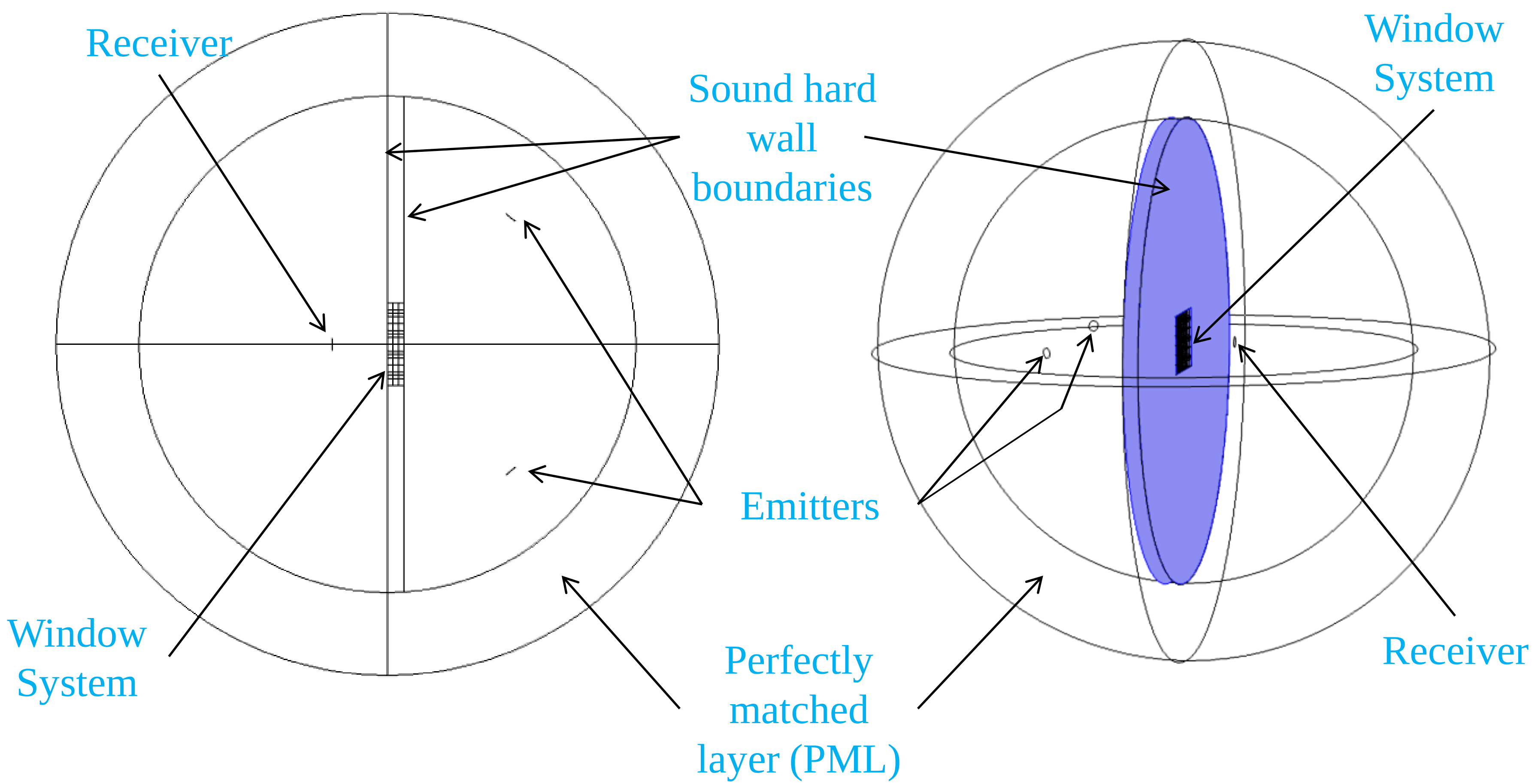


Image courtesy: Kim & Lee [1]

- In the physical tests conducted by Kim & Lee [1], two emitters were place diagonally at ~100° and 120 mm away from the window.
- A receiver was placed on the other side of the window.
- A wall surrounding the window system separated the receiver from the emitters.
- The emitters emitted sound wave at 80 dB with frequencies between 400 Hz and 5 kHz.
- Transmission loss was then calculated based on the sound level reduction at the receiver end.

Model Geometry inside COMSOL

<u>(i) Plan View</u> **<u>(ii) Isometric (3D) View</u>**



Boundary Conditions

- Acoustic-Shell Interaction Physics inside COMSOL was utilised to model the acoustic response of the window system.
- Shell boundaries were used to describe the window domains and the change thickness sub-node was used to state the thickness of each atom.
- The emitters were described as monopole sources emitting 80 dB sound level.
- The wall surrounding the window was described as sound hard boundary so that the receiver does not pick up sound directly from the emitters.
- The air filter was modelled using interior perforated plate condition.
- The parameters of the air filter used in the model is given below:

DESCRIPTION	UNIT	VALUE
Pore size	mm	0.2
Area Porosity	1	0.008
Plate Thickness	mm	1

- A perfectly matched layer was applied to the outer domains of air to avoid sound reflections back into the system.
- Surface integral probes were utilised to measure the transmission loss of the window system.

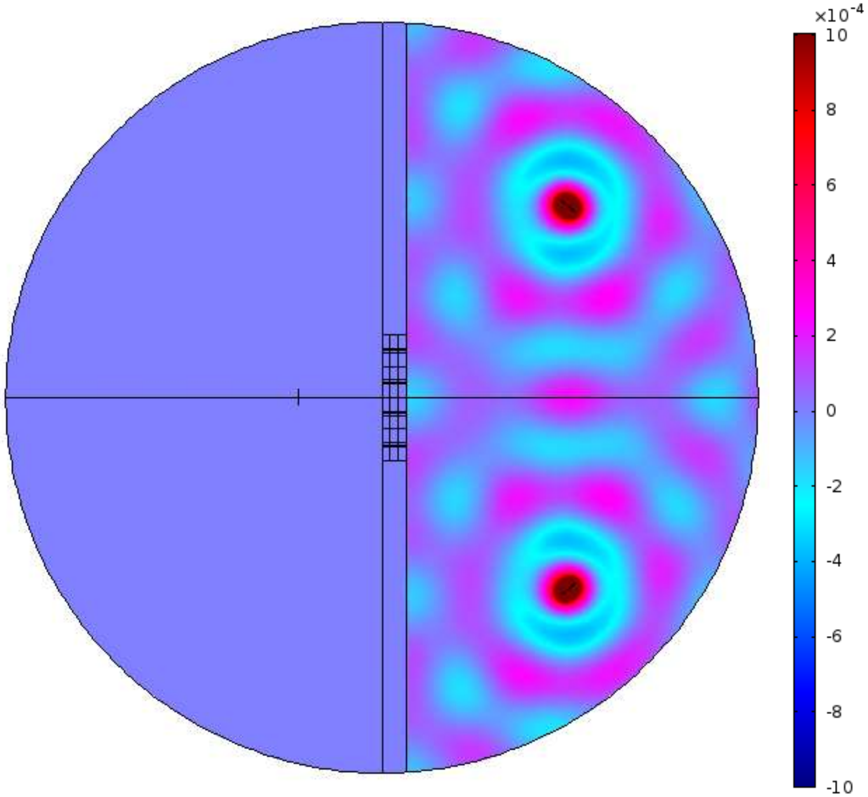
Eigenfrequency Analysis Results

- An eigenfrequency analysis of both A-type and B-type window was conducted to observe the resonance of the window system.
- This was necessary to achieve the negative bulk modulus of the system.
- The following resonance frequencies were obtained after the analysis run of both A-type and B-type window:

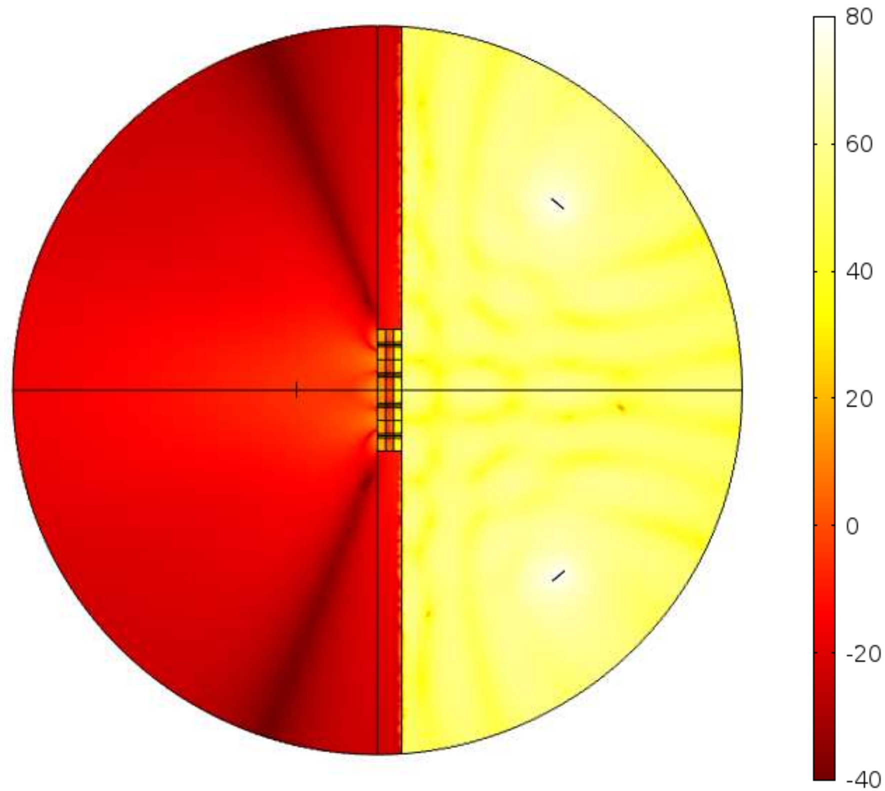
Window Type	**No. of Chambers**	**Resonance Frequency**	
		COMSOL Model	Kim & Lee[1]
A	1	500	590
	2	872	700
	4	1072	830
B	1	764	770
	2	951	910
	4	1600	n/a

Frequency Domain Analysis Results

- A frequency domain analysis for frequency ranges between 400 Hz to 5 kHz was run first on the A-type (Ø 20mm air hole) window system.
- The acoustic response and sound pressure level (SPL) at 770 Hz is shown below.

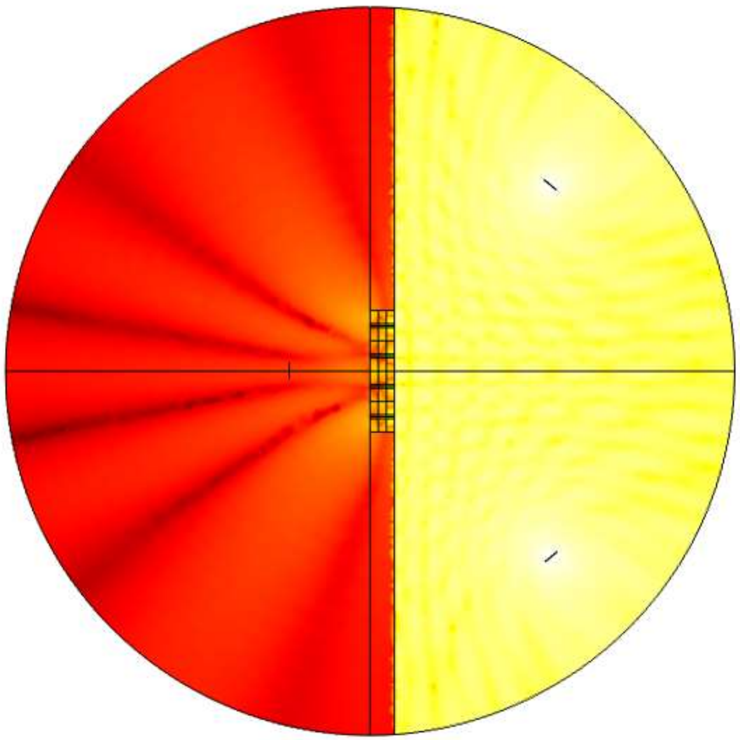


(a) Acoustic Pressure (Pa) at 770 Hz

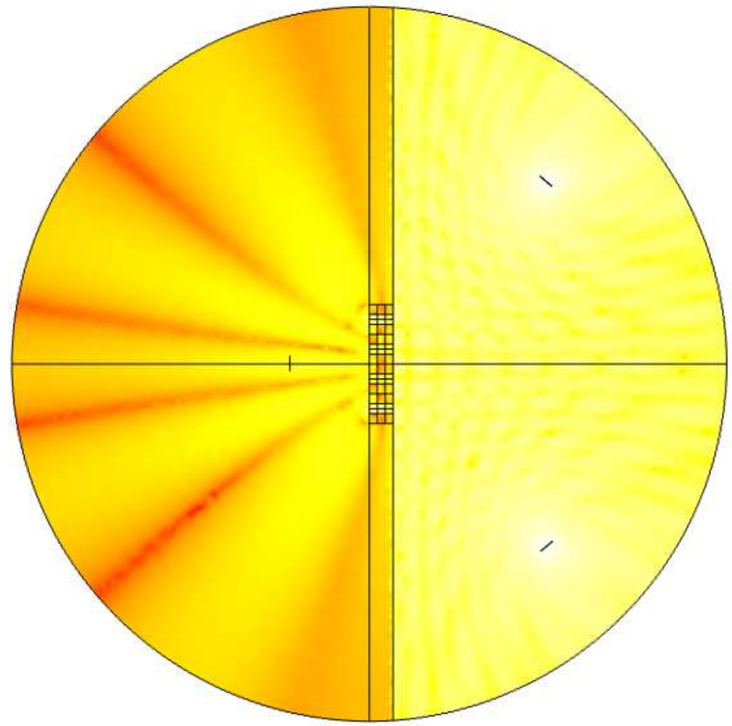


(b) Sound Pressure Level (dB) at 770 Hz

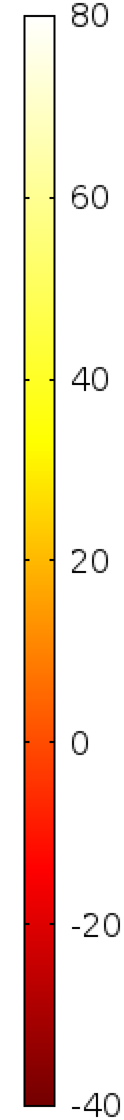
Comparison of A-type & B-type



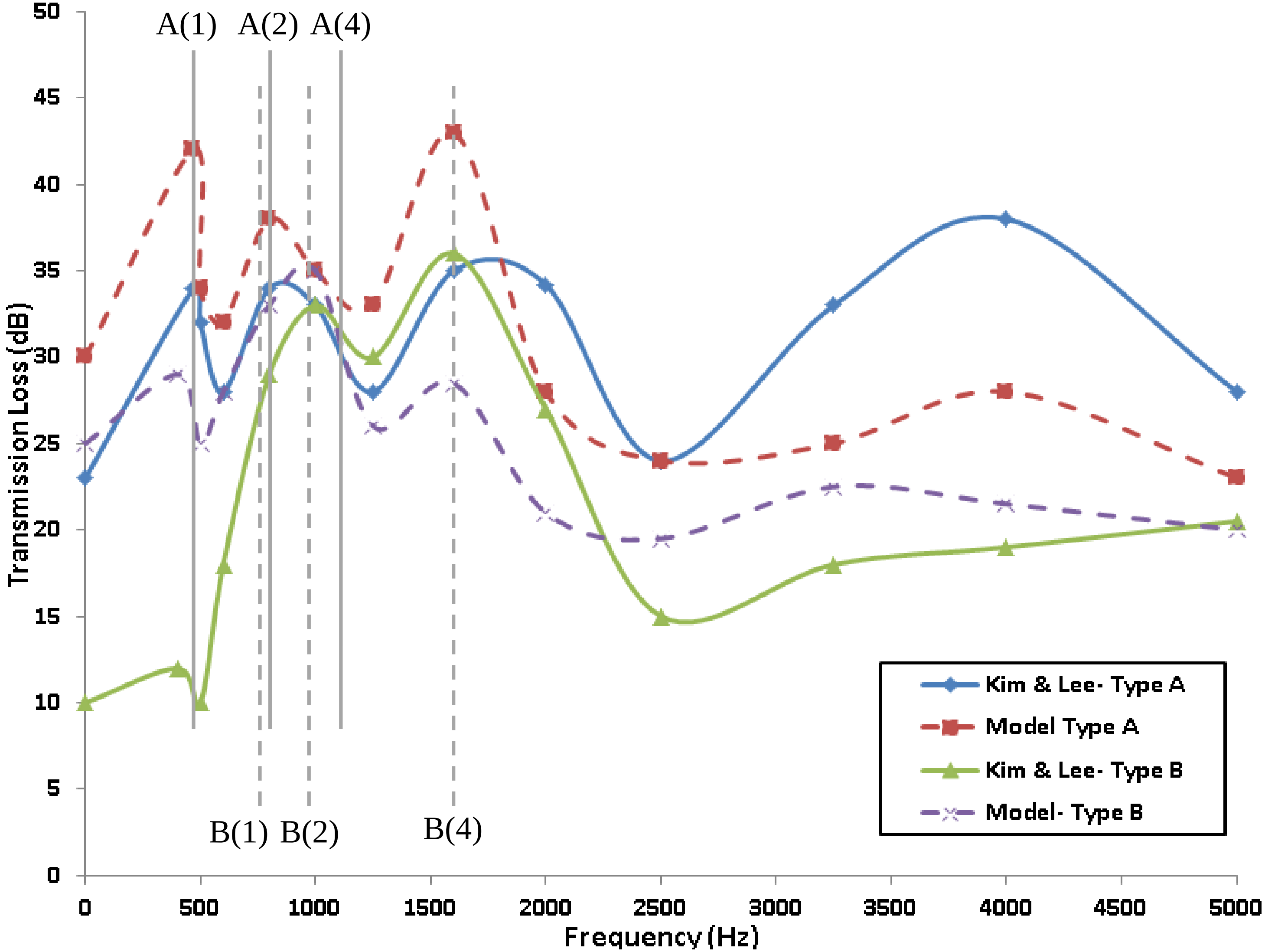
(a) Sound pressure level at (dB) 1800 Hz for A-type



(b) Sound Pressure level (dB) at 1800 Hz for B-type



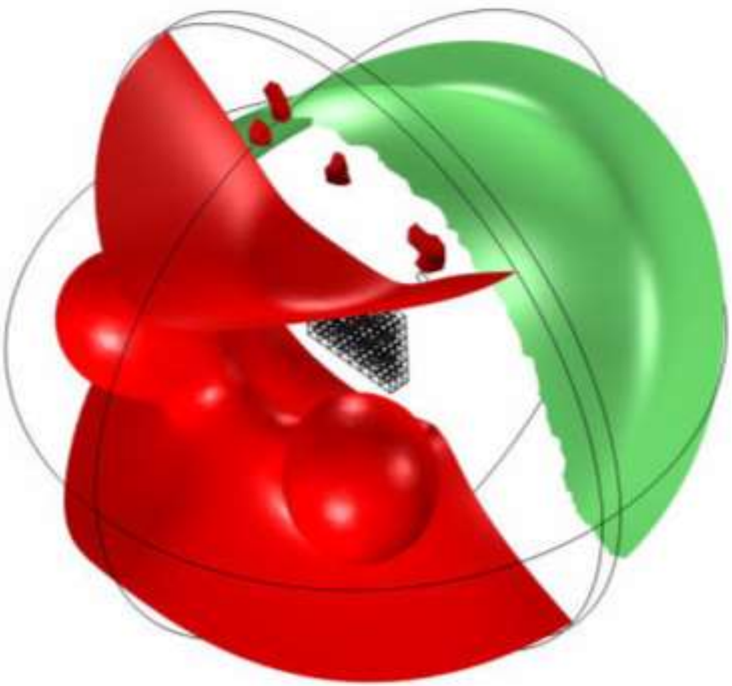
Transmission Losses from Models



Discussions & Conclusions

- An air transparent soundproof window system was developed & modelled in COMSOL Multiphysics based on the works presented by Kim & Lee [1].
- Two types of window system were analysed:
  - A-type (Ø 20 mm air hole)
  - B-type (Ø 50 mm air hole)
- The window system consisted of several atoms with different number of chambers in each layer.
- Each atom replicated the acoustic effects of a modified Helmholtz resonator.
- Acoustic transmission loss from the model simulations were compared against the physical test data provided by Kim & Lee [1].
- The overall acoustic trends for both A-type & B-type windows were consistent with that observed in the physical test data provided.
- The observed variations in transmission loss can be accounted for due to the unknown filter parameters like porosity & material properties.
- Additionally, the surrounding wall and the window frame were ideally modelled as sound hard boundaries in the COMSOL model.

Future Works



- Optimising the constraints of the triple glazed free air flow window.
- Optimisation constraints include:
  - Reduction in the thickness of the overall window.
  - Increase the air flow but at the same time attenuate sound frequencies.
  - Increase the frequency ranges for which the sound can be attenuated.

References

[1] Sang-Hoon Kim and Seong-Hyun Lee, arXiv: 1307.0301[cond-mat.mtrl-sci] (2013)

[2] COMSOL Multiphysics, Acoustics Module Physics Interface Guide Version 4.4, COMSOL AB (2013)

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