STUDIO
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Studio Sound Service is an acoustic design firm, located in Florence, Italy.
Since 1983 we design rooms for music and audio/video production.

Some Projects:

- Barys Arena (ice hockey) @ Astana, Kazakhstan;
- FOX post-production studios @ Münich (DE);
- FOX post-production studios @ Hammersmith, London (UK);
- D:POT Recording Arts @ Prato – Fabrizio Simoncioni;
- Mulinetti Studio @ Genova – Alberto Parodi (Resolution Award 2015 Best Audio Facility, Nomination);
- The Garage @ Civitella v.d.C. (AR) (Resolution Award 2014 Best Audio Facility, Nomination);
- House of Glass @ Viareggio (LU) – Gianni Bini (Resolution Award 2013 Best Audio Facility, Nomination);
- Damian Lazarus – Monastic Studio @ Vicchio (FI);
- Vinai Studio @ Brescia;
- Renato Zero Studio @ Roma;
- PPG Studios (Andrea Bocelli) @ S. Pietro Belvedere (PI);
- In House (Dolby® approved - Sorrentino) @ Roma;
- George Lucas Home Theater, Italy;
- Chiesa di Santa Maria Nuova (Arch. Mario Botta) @ Terranuova Bracciolini (AR);
- Prada Auditorium and Conference Room via Orobia @ Milano;
- Sala Proiezioni Museo Ferrari @ Maranello (MO).

Donato Masci
Acoustic designer & Consultant

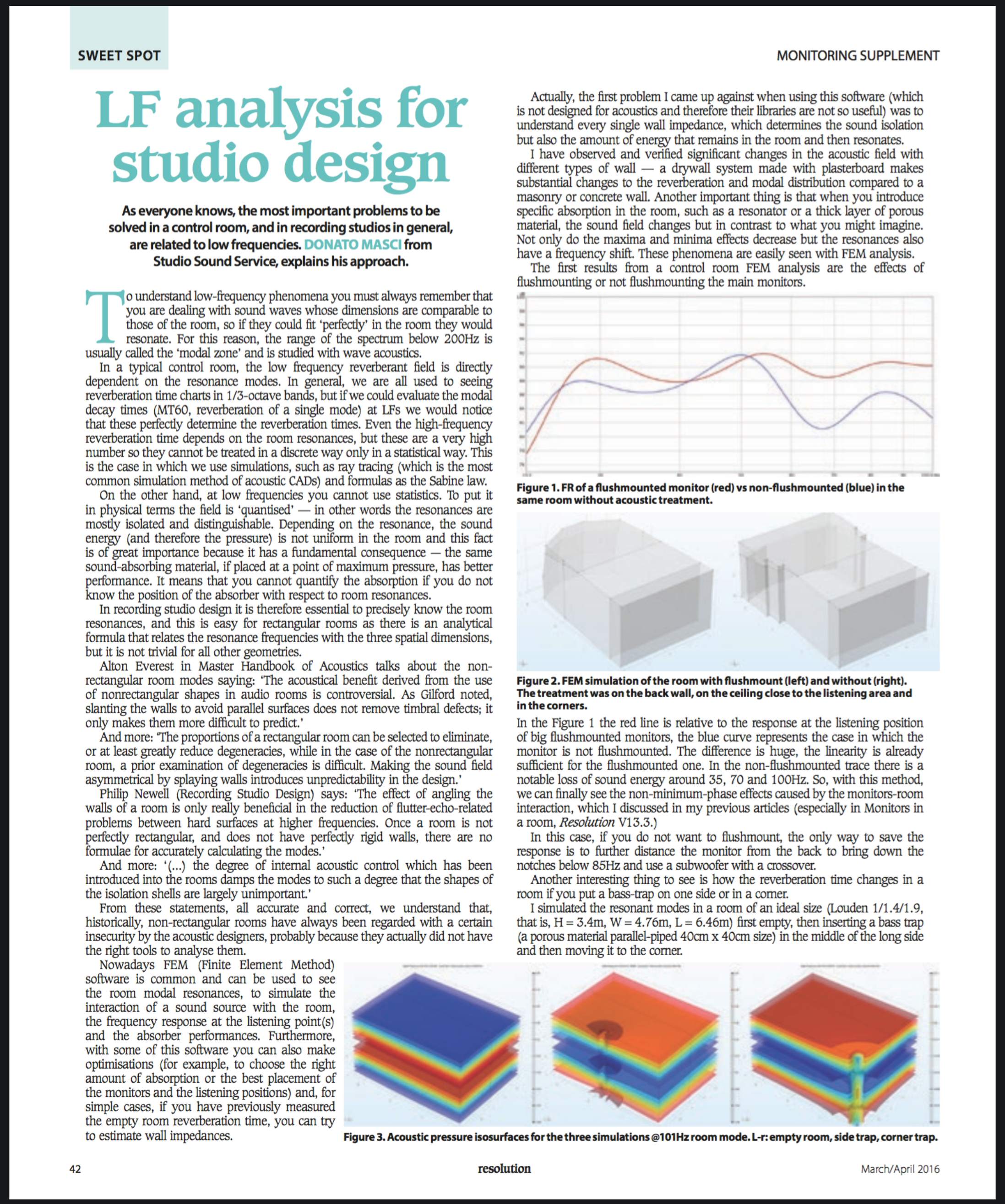
15/09
— 2017

Low Frequency Analysis for recording studio design

Resolution Magazine (UK)

March/April 2016 – Monitoring Supplement

LF analysis for studio design



SWEET SPOT

MONITORING SUPPLEMENT

LF analysis for studio design

As everyone knows, the most important problems to be solved in a control room, and in recording studios in general, are related to low frequencies. DONATO MASCI from Studio Sound Service, explains his approach.

To understand low-frequency phenomena you must always remember that you are dealing with sound waves whose dimensions are comparable to those of the room, so if they could fit 'perfectly' in the room they would resonate. For this reason, the range of the spectrum below 200Hz is usually called the 'modal zone' and is studied with wave acoustics.

In a typical control room, the low frequency reverberant field is directly dependent on the resonance modes. In general, we are all used to seeing reverberation time charts in 1/3-octave bands, but if we could evaluate the modal decay times (MT60, reverberation of a single mode) at LFs we would notice that these perfectly determine the reverberation times. Even the high-frequency reverberation time depends on the room resonances, but these are a very high number so they cannot be treated in a discrete way only in a statistical way. This is the case in which we use simulations, such as ray tracing (which is the most common simulation method of acoustic CADs) and formulas as the Sabine law.

On the other hand, at low frequencies you cannot use statistics. To put it in physical terms the field is 'quantised' — in other words the resonances are mostly isolated and distinguishable. Depending on the resonance, the sound energy (and therefore the pressure) is not uniform in the room and this fact is of great importance because it has a fundamental consequence — the same sound-absorbing material, if placed at a point of maximum pressure, has better performance. It means that you cannot quantify the absorption if you do not know the position of the absorber with respect to room resonances.

In recording studio design it is therefore essential to precisely know the room resonances, and this is easy for rectangular rooms as there is an analytical formula that relates the resonance frequencies with the three spatial dimensions, but it is not trivial for all other geometries.

Alton Everest in Master Handbook of Acoustics talks about the non-rectangular room modes saying: 'The acoustical benefit derived from the use of nonrectangular shapes in audio rooms is controversial. As Gilford noted, slanting the walls to avoid parallel surfaces does not remove timbral defects; it only makes them more difficult to predict.'

And more: 'The proportions of a rectangular room can be selected to eliminate, or at least greatly reduce degeneracies, while in the case of the nonrectangular room, a prior examination of degeneracies is difficult. Making the sound field asymmetrical by splaying walls introduces unpredictability in the design.'

Philip Newell (Recording Studio Design) says: 'The effect of angling the walls of a room is only really beneficial in the reduction of flutter-echo-related problems between hard surfaces at higher frequencies. Once a room is not perfectly rectangular, and does not have perfectly rigid walls, there are no formulae for accurately calculating the modes.'

And more: '(...) the degree of internal acoustic control which has been introduced into the rooms damps the modes to such a degree that the shapes of the isolation shells are largely unimportant.'

From these statements, all accurate and correct, we understand that, historically, non-rectangular rooms have always been regarded with a certain insecurity by the acoustic designers, probably because they actually did not have the right tools to analyse them.

Nowadays FEM (Finite Element Method) software is common and can be used to see the room modal resonances, to simulate the interaction of a sound source with the room, the frequency response at the listening point(s) and the absorber performances. Furthermore, with some of this software you can also make optimisations (for example, to choose the right amount of absorption or the best placement of the monitors and the listening positions) and, for simple cases, if you have previously measured the empty room reverberation time, you can try to estimate wall impedances.

Actually, the first problem I came up against when using this software (which is not designed for acoustics and therefore their libraries are not so useful) was to understand every single wall impedance, which determines the sound isolation but also the amount of energy that remains in the room and then resonates.

I have observed and verified significant changes in the acoustic field with different types of wall — a drywall system made with plasterboard makes substantial changes to the reverberation and modal distribution compared to a masonry or concrete wall. Another important thing is that when you introduce specific absorption in the room, such as a resonator or a thick layer of porous material, the sound field changes but in contrast to what you might imagine. Not only do the maxima and minima effects decrease but the resonances also have a frequency shift. These phenomena are easily seen with FEM analysis.

The first results from a control room FEM analysis are the effects of flushmounting or not flushmounting the main monitors.

Figure 1. FR of a flushmounted monitor (red) vs non-flushmounted (blue) in the same room without acoustic treatment.

Figure 2. FEM simulation of the room with flushmount (left) and without (right). The treatment was on the back wall, on the ceiling close to the listening area and in the corners.

In the Figure 1 the red line is relative to the response at the listening position of big flushmounted monitors, the blue curve represents the case in which the monitor is not flushmounted. The difference is huge, the linearity is already sufficient for the flushmounted one. In the non-flushmounted trace there is a notable loss of sound energy around 35, 70 and 100Hz. So, with this method, we can finally see the non-minimum-phase effects caused by the monitors-room interaction, which I discussed in my previous articles (especially in Monitors in a room, *Resolution* V13.3.)

In this case, if you do not want to flushmount, the only way to save the response is to further distance the monitor from the back to bring down the notches below 85Hz and use a subwoofer with a crossover.

Another interesting thing to see is how the reverberation time changes in a room if you put a bass-trap on one side or in a corner.

I simulated the resonant modes in a room of an ideal size (Louden 1/1.4/1.9, that is, H = 3.4m, W = 4.76m, L = 6.46m) first empty, then inserting a bass trap (a porous material parallel-piped 40cm x 40cm size) in the middle of the long side and then moving it to the corner.

Figure 3. Acoustic pressure isosurfaces for the three simulations @101Hz room mode. L-r: empty room, side trap, corner trap.

42 resolution March/April 2016

My first experience with a FEM simulation (COMSOL):

working as room acoustic consultant and then as coordinator of an R&D project with **B&C Speakers**, **Powersoft** and **K-Array**.

B&C Speakers R&D uses **COMSOL** for their transducers design, so we start using for a room acoustic project about active absorbers.

We did a lot of measurements in a lab an found a very good correlation between FEM simulation.
(we can easily appreciate a temperature difference…!)

How to **design** a **recording studio?** *(before FEM…)*

A. CAD acoustic software (EASE, CATT, ODEON) can't work below 100 Hz so they cannot simulate the modal response of a room.

B. Basic physics and trial and error experience brings to some "golden rules" and design, such as LEDE and Non-Environment.

→ So, nobody can really know what happens at LF if you can't design in a "golden shaped" room.

Donato Masci

Recording studio design history

1950
First control rooms
(random design corner, etc.)

'60
Tom Hidley
(first bass trap)

1978
Tom Hidley - Westlake
Time Delay Spectrometry

1979
Chips and Don Davis
LEDE design

1984
RFZ Reflection free zone

1990
Bob Walker (BBC)
Controlled Image Design CID

1991
Tom Hidley, Philip Newel
Non-Environment

1890 — 1960 — 1970 — 1980 — 1990 — 2000

AM Radio
Electrical Phonographs

Reel to Reel

Primo stereo

Dolby Cassettes

MP3, AC3, DTS 96/24
DVD-A, SACD

5.1 compressed

1886 Tainter & Bell:
Invenzione del grammofono (registrazione su disco)

1901 Prima trasmissione radio transatlantica

1914 Ford "T"
Prima Autoradio

1904 Marconi:
Brevetto radio

1926 John Logie Baird
Invenzione della Televisione

1933 Armstrong
Invenzione dell'FM

1936 Magnetophone
Primo registratore a nastro magnetico

1948 Introdu

1949 AMPE

1954 Prim
portabile

1952 Re

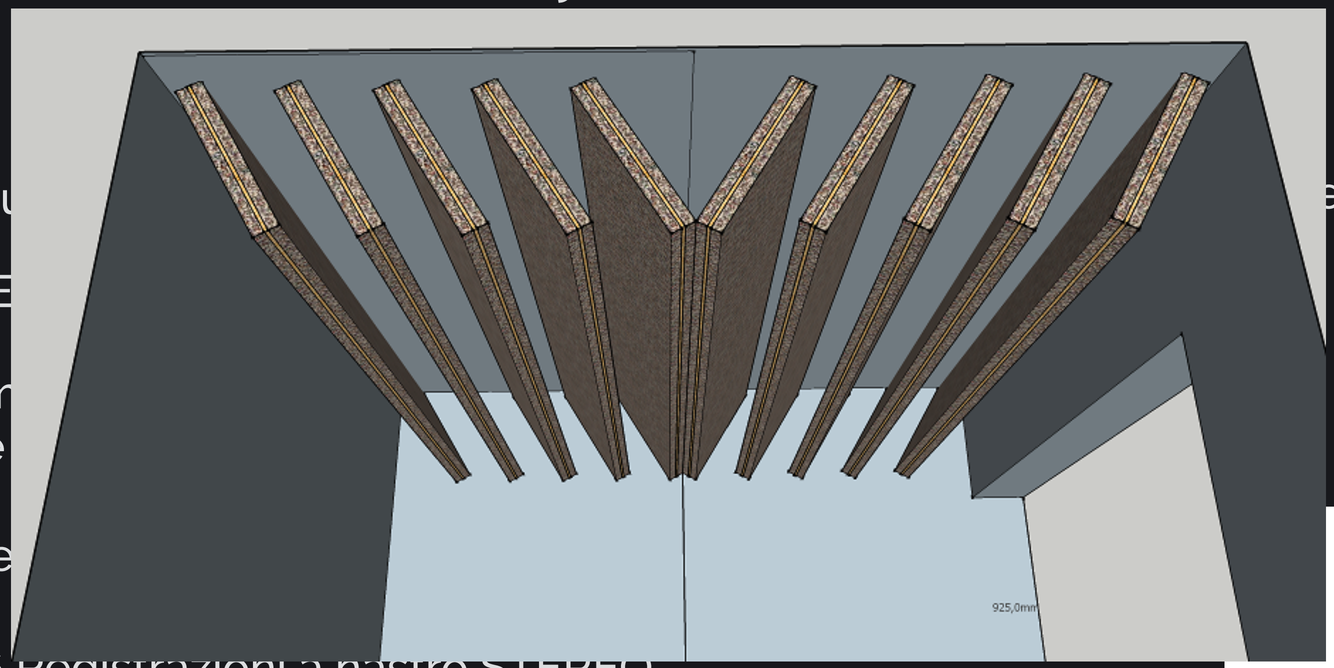
1956 Registrazioni a nastro STEREO

1958 Primo LP STEREO

1962 Philips
Compact Cassette Tape

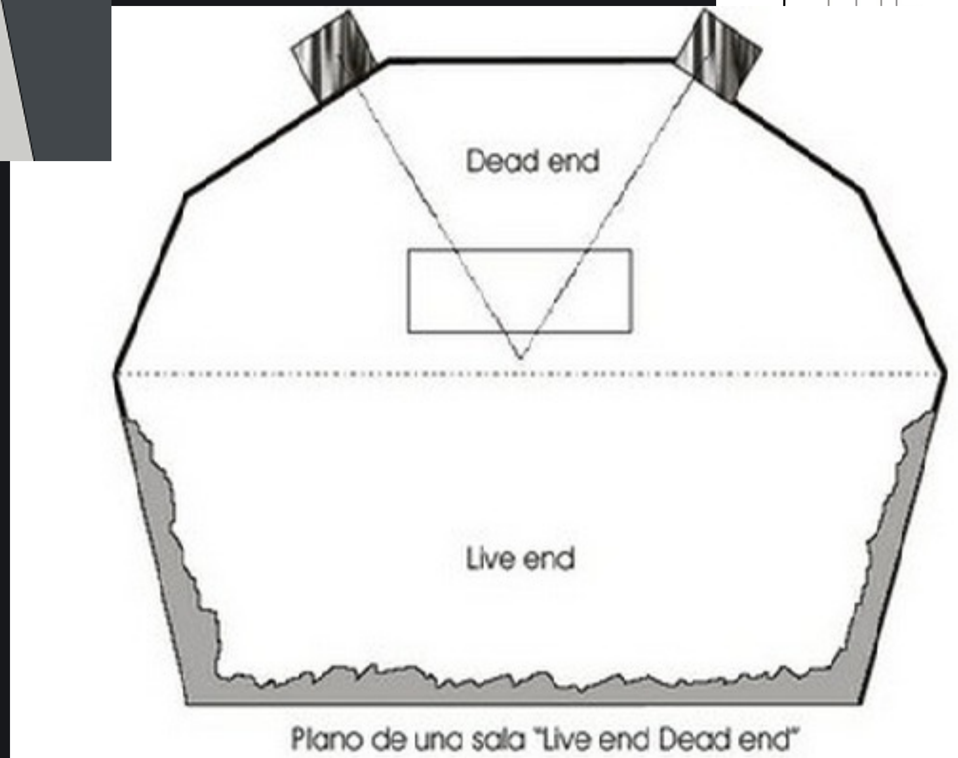
1967 TV Color in UK

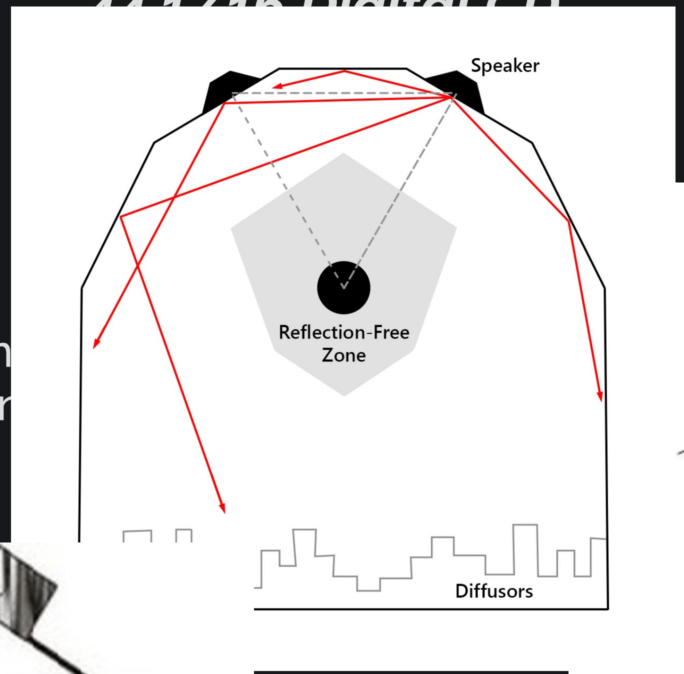
1969 Dolby-B noise reduction



essore CPU

1978 Son
Walkmar





& Philips
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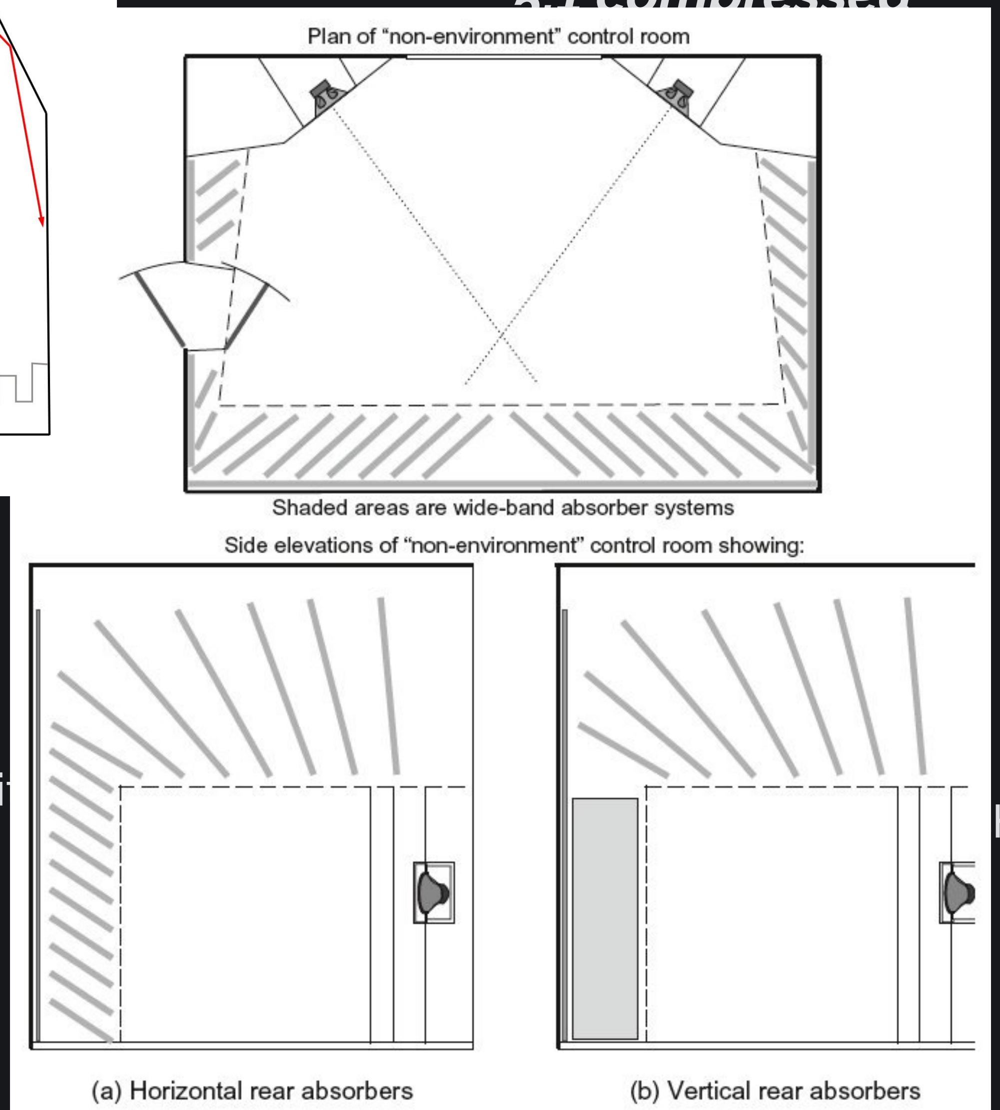

haring

Main problems about Low Frequencies

A. Room Modes:
very different SPL in the FR
between maxima and minima
(about 20-30 dB)

B. Loudspeaker-Room interaction:
non minimum phase effects
FR dips and problems at LF

→ we really need to know what happens at LF changing the room design and size

Studio building costs K€

	1995		2005	2008	2010	2014
Top	200÷1000	200÷1000	200÷1000	200÷750	150÷750	100÷750
Project	-	25÷200	25÷200	25÷200	20÷150	20÷100
Home	-	-	8÷25	8÷25	8÷20	8÷20

Studio audio equipment costs K€

	1995		2005	2008	2010	2014
Top	500÷1000	500÷1000	250÷800	200÷800	150÷500	100÷500
Project	-	20	50÷250	30÷200	30÷150	25÷100
Home	-	-	10÷50	8÷30	5÷30	5÷25

So the studios are getting cheaper and … smaller!

—> we need to find different (and **good**) designs also for smaller rooms.

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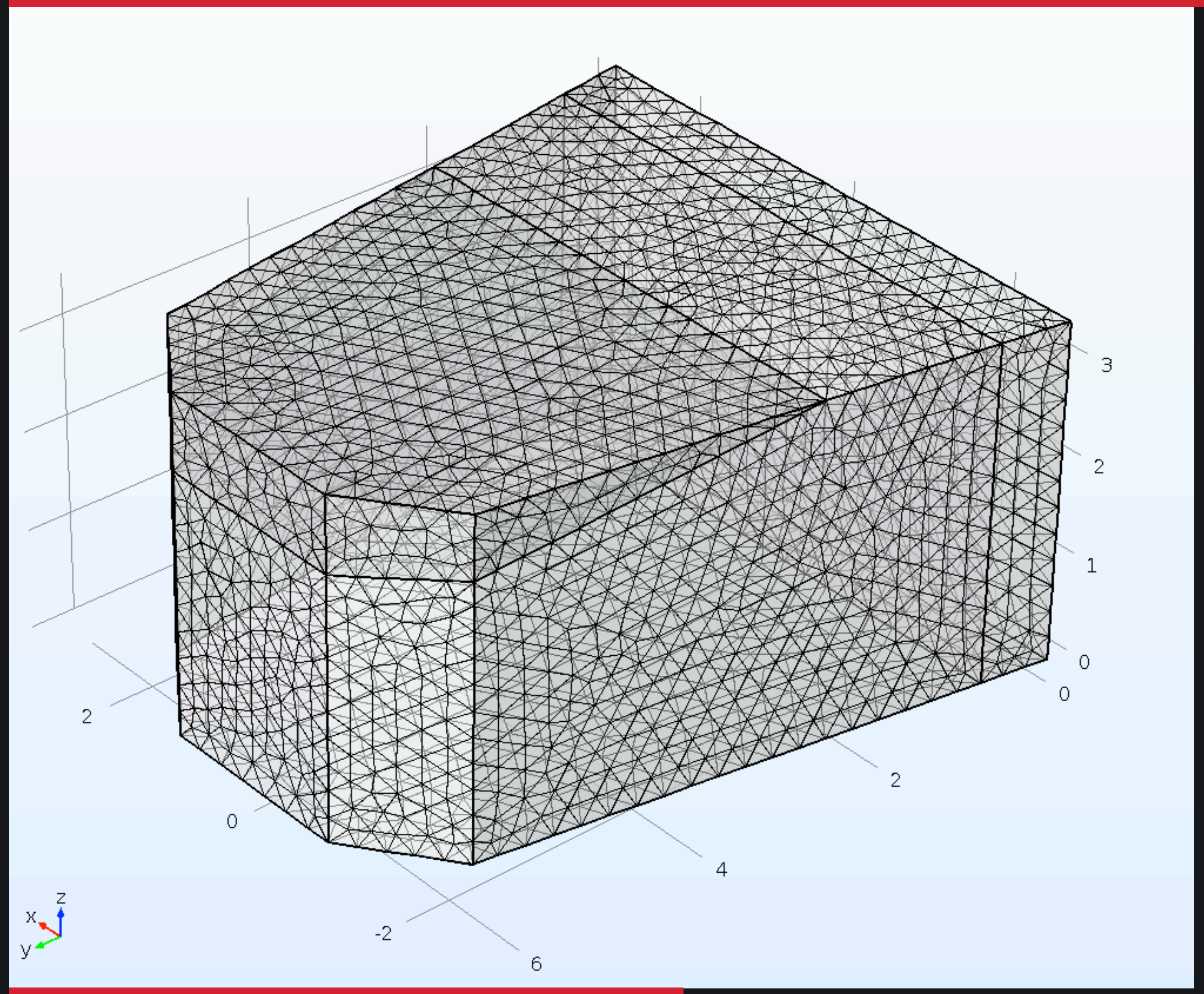
Case study

CASE 1. Room modes

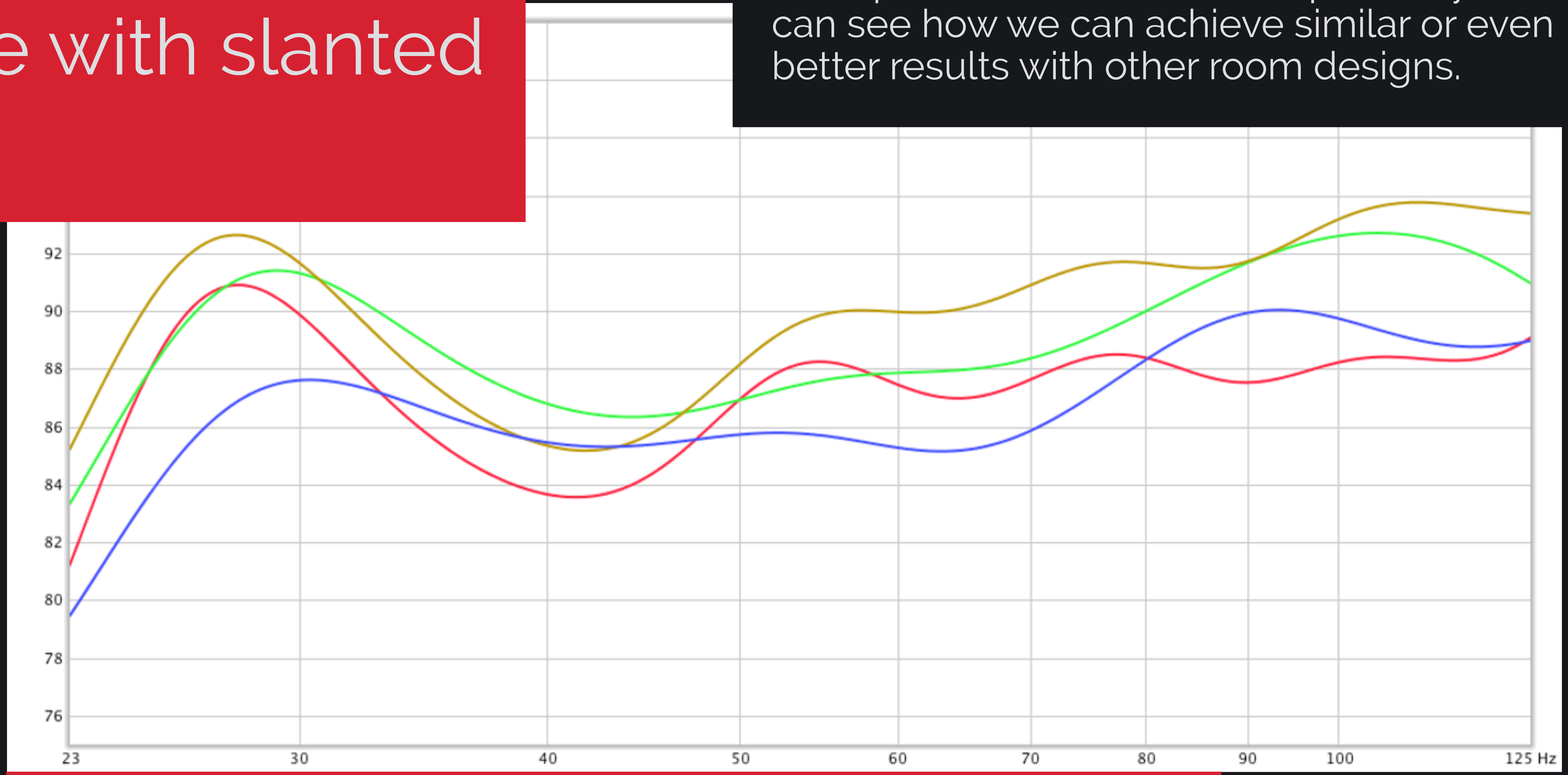
Comparison between an “optimal dimension” rectangular room (Louden 1/1.4/1.9, H=3.4m, W=4.76m, L=6.46m), VS a similar non-rectangular one with slanted symmetrical walls.

It is notable that the ‘Slanted room’ has more sound energy at LF and that treatment in both cases serves to minimise the cancellation to 40Hz and to linearise the response.

It is wrong to think that an optimally-sized room already has a perfect FR without absorption, and from this comparison you can see how we can achieve similar or even better results with other room designs.



Mesh for COMSOL



FR of a Rectangular (Louden) room untreated (red) and treated (blue) VS. non-rectangular (Louden “slanted”) untreated (brown) and treated (green).

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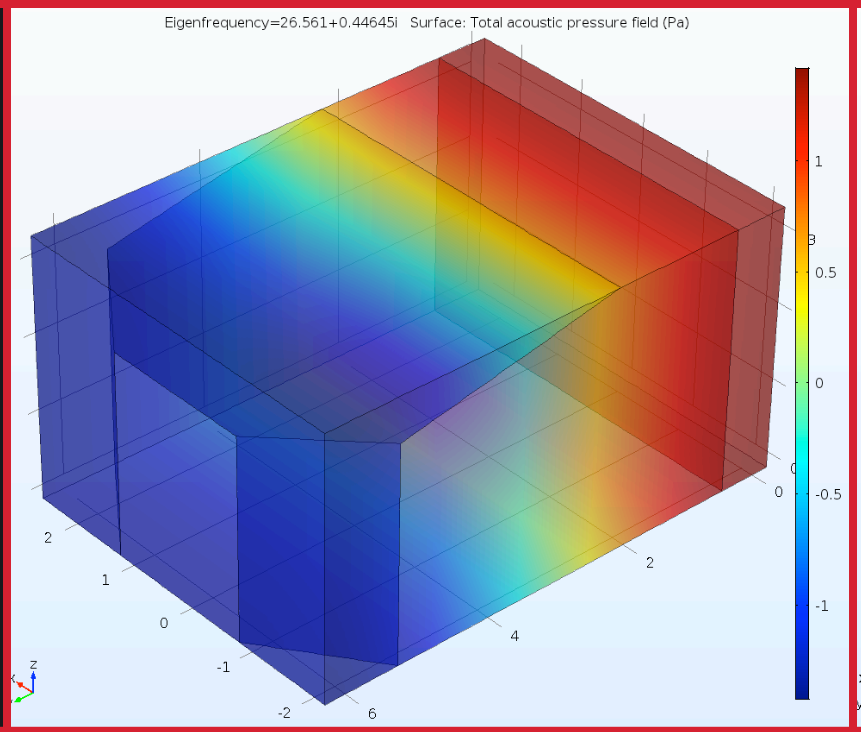
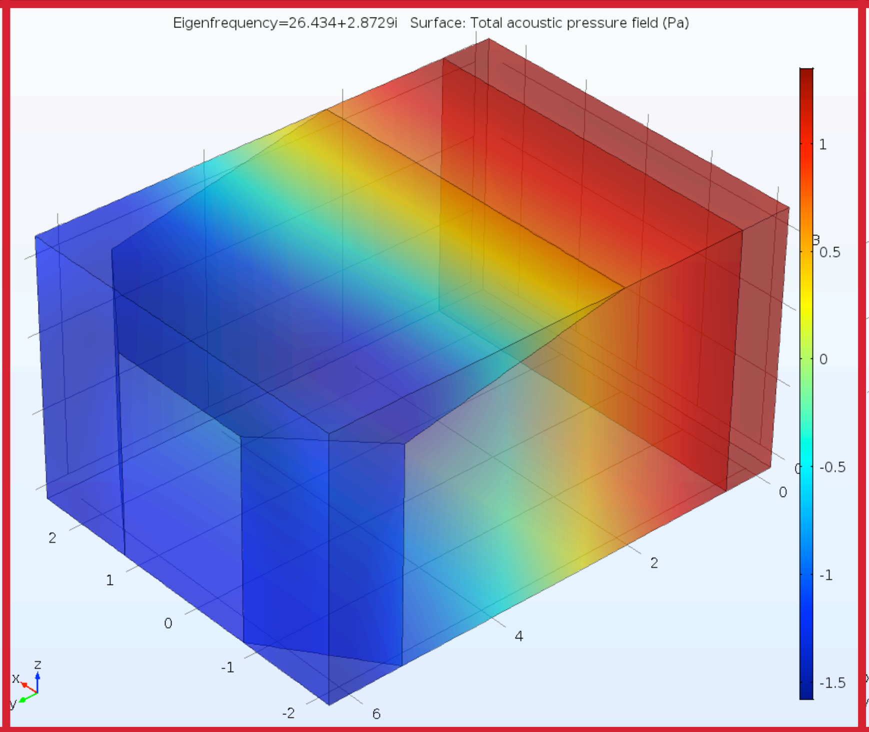
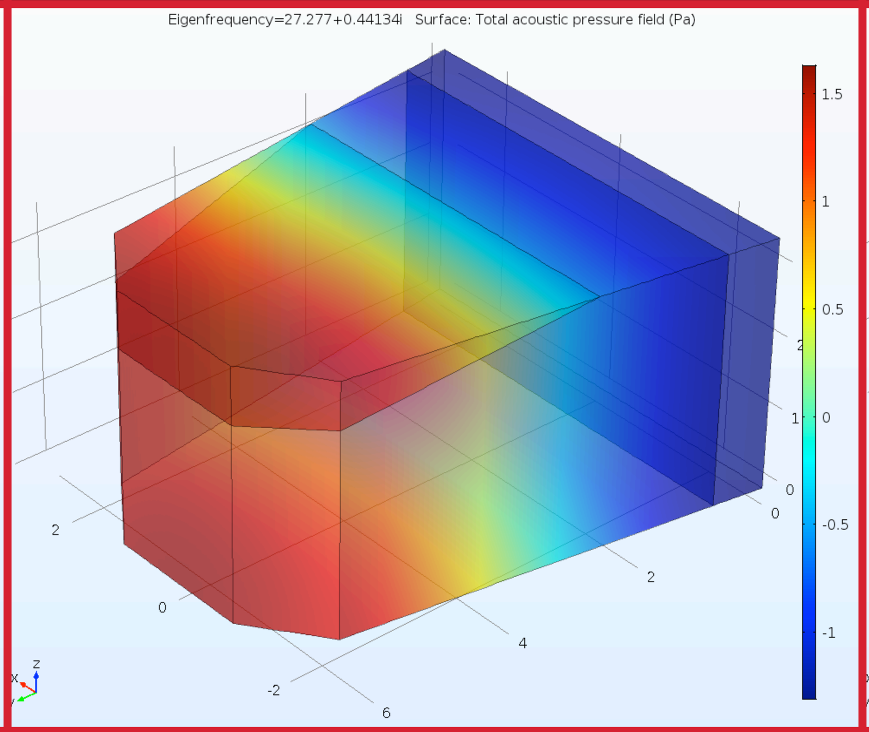
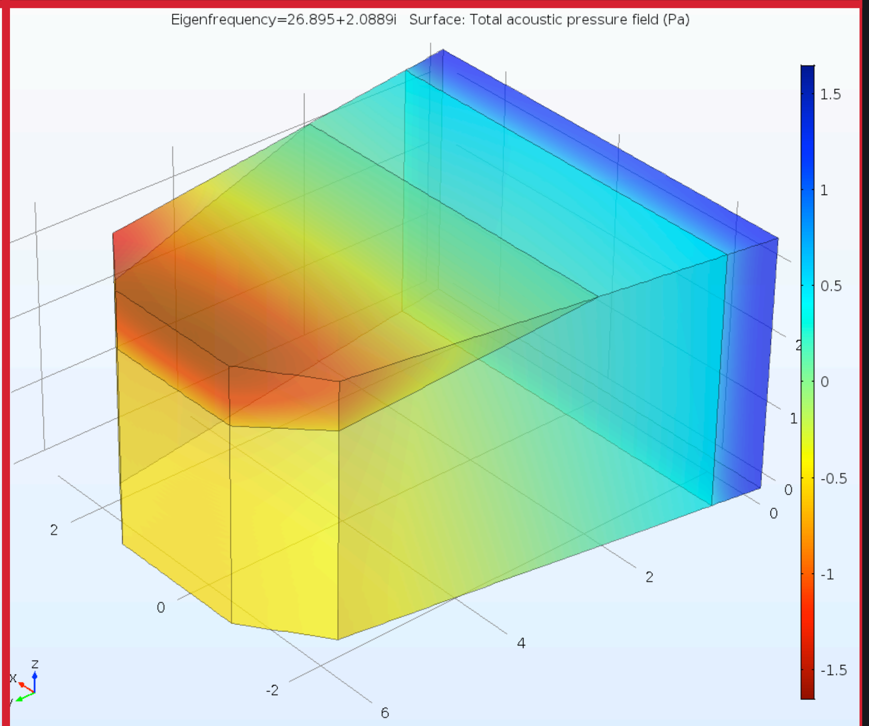
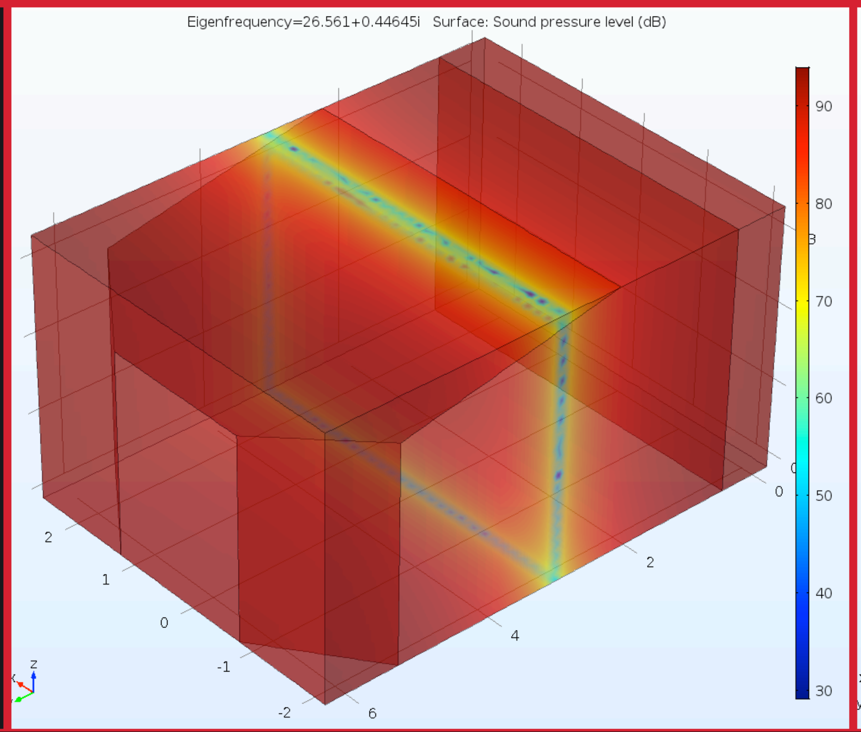
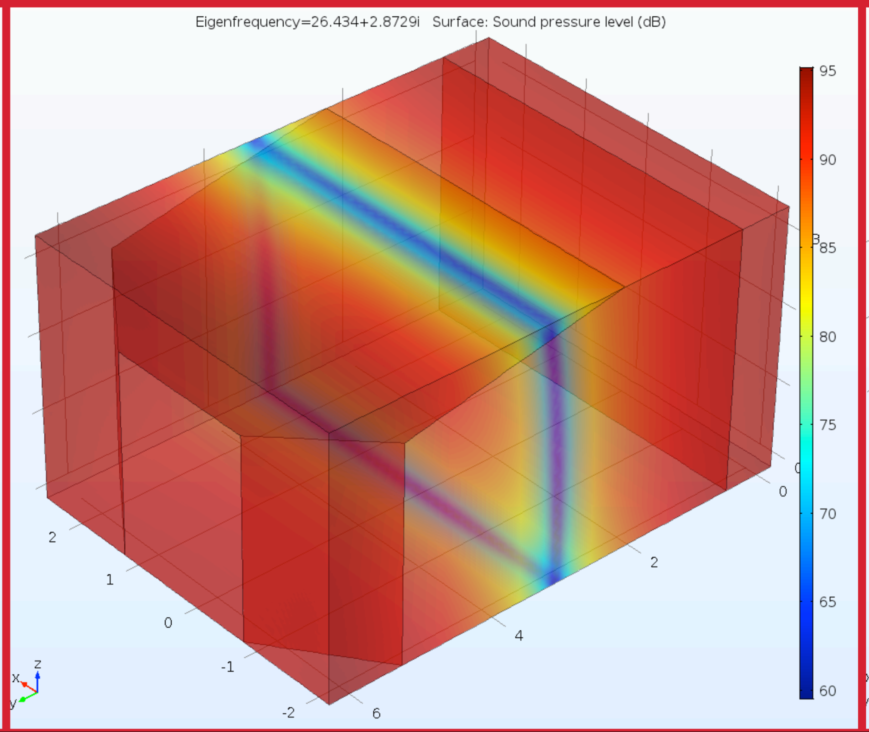
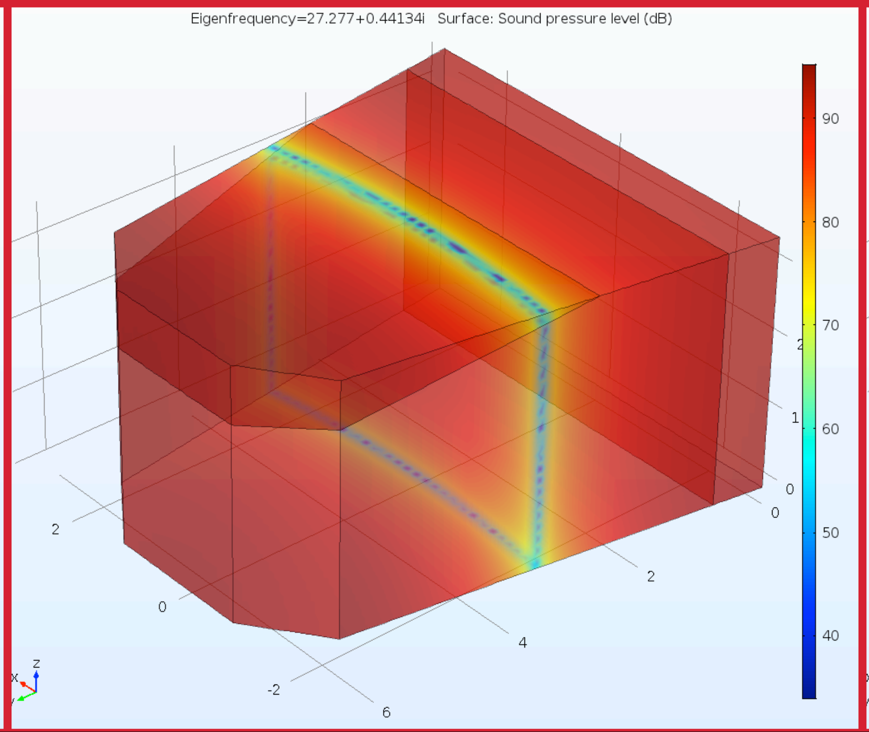
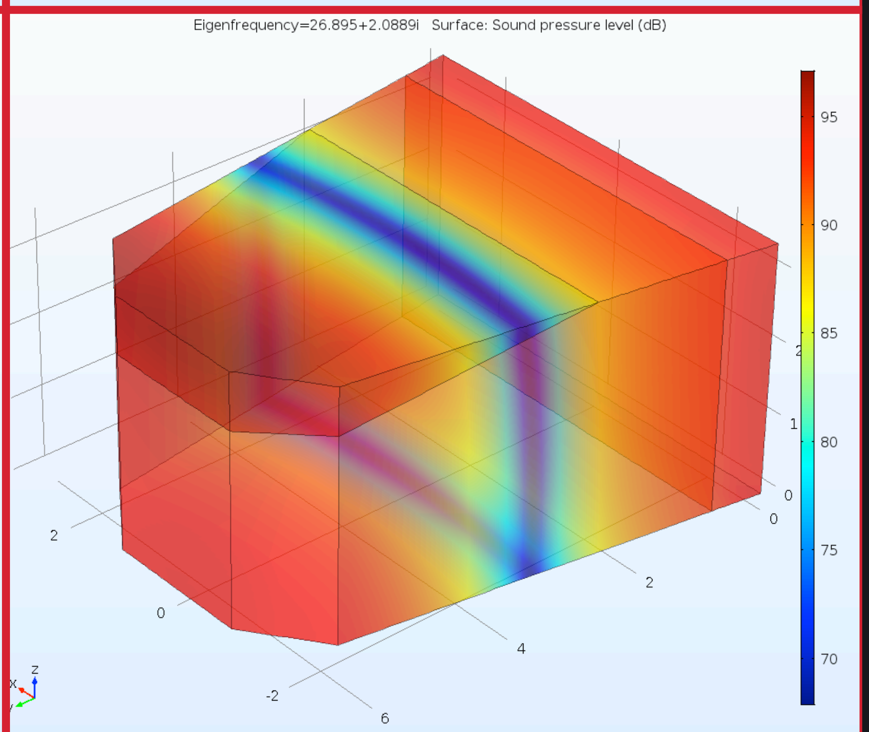
“Optimal” rectangular room VS non rectangular one

Note the reduction of modal decay time in the treated cases and the frequency shift of the resonance frequencies, but the most interesting result is that, in the treated configurations, the sound pressure distribution is much more homogeneous.

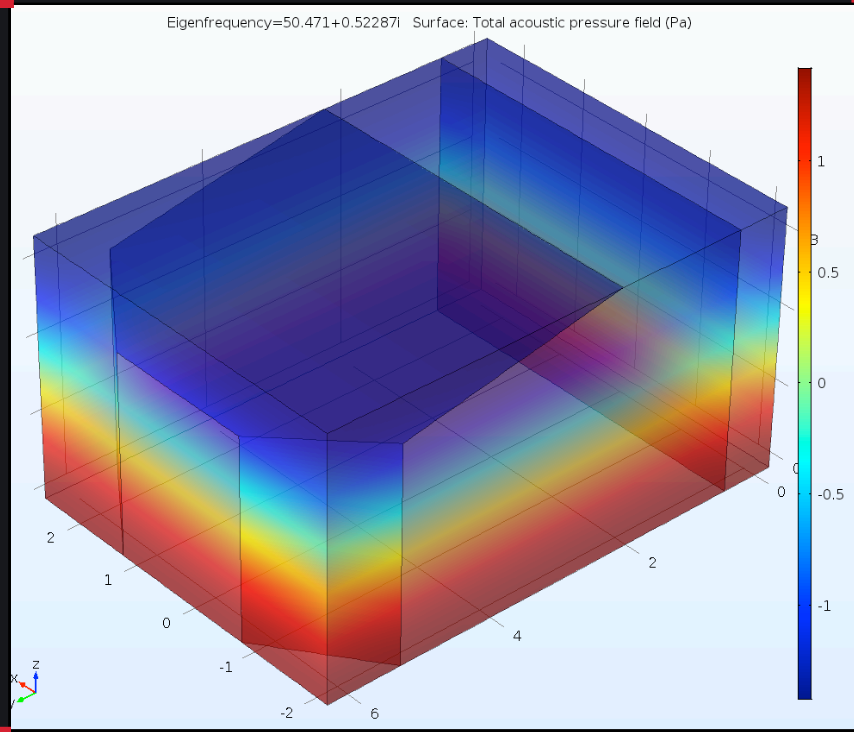
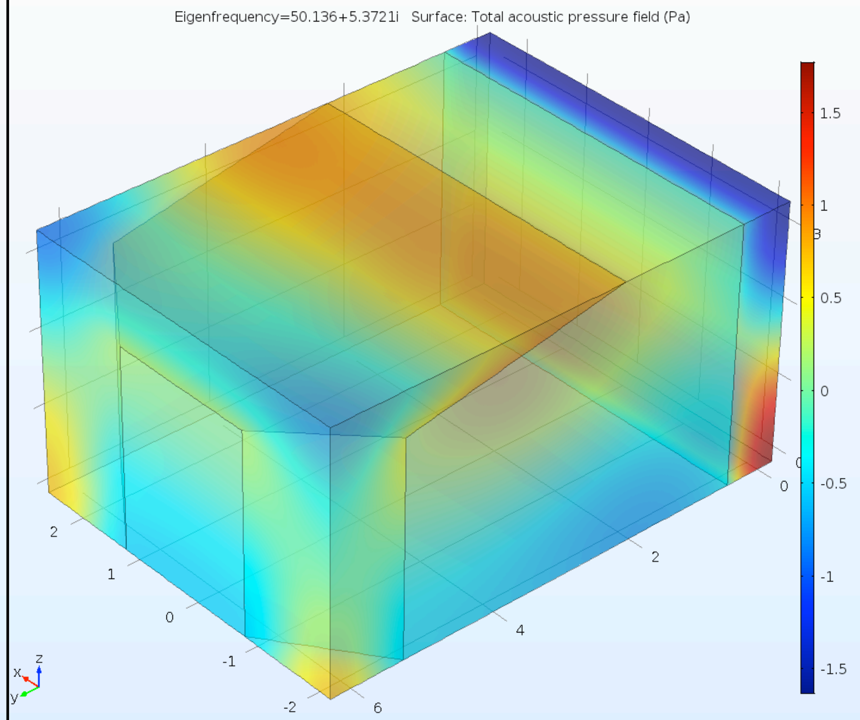
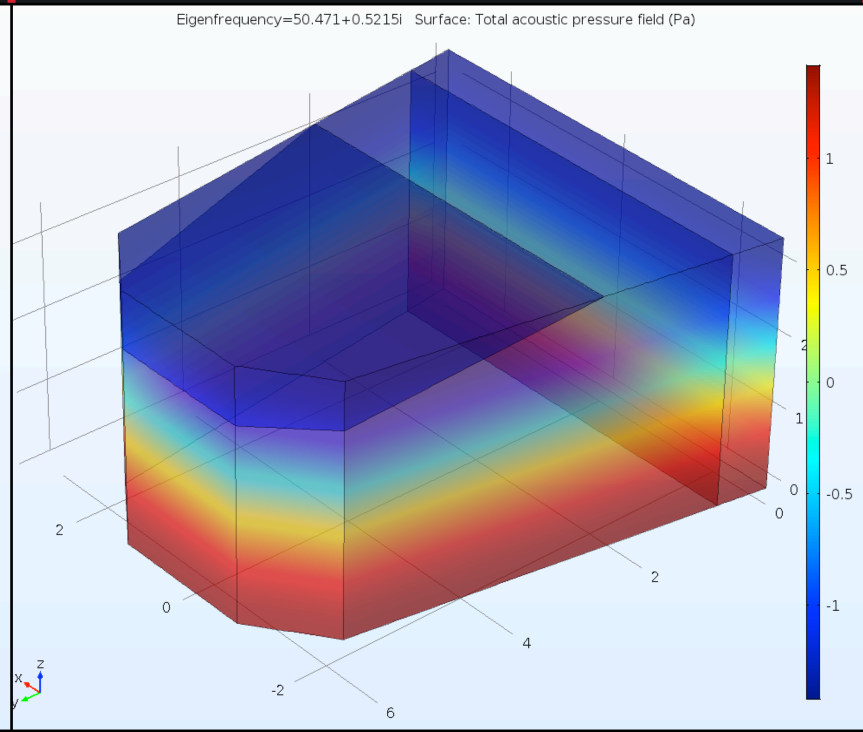
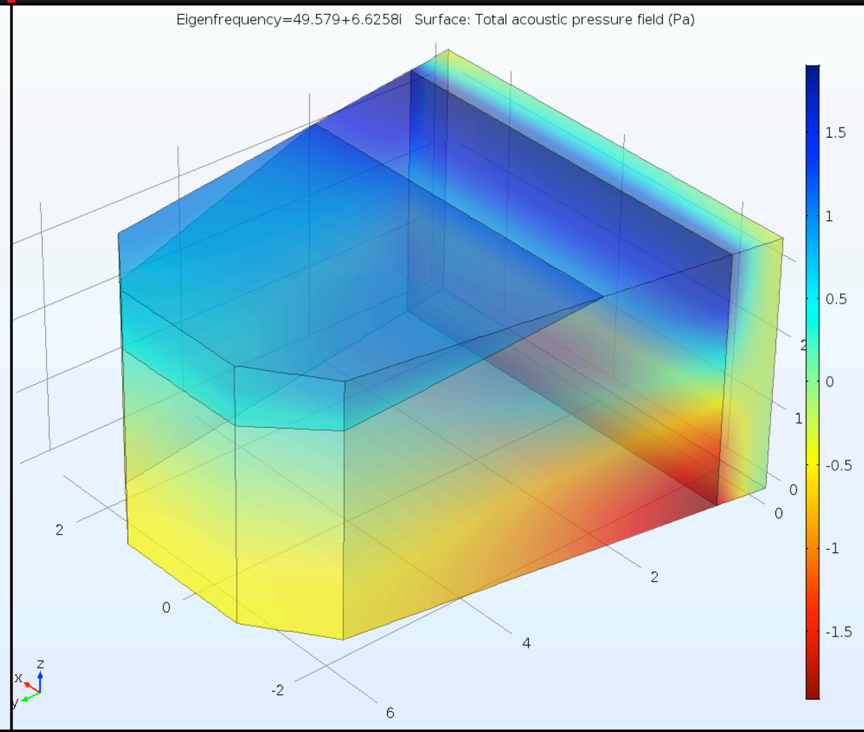
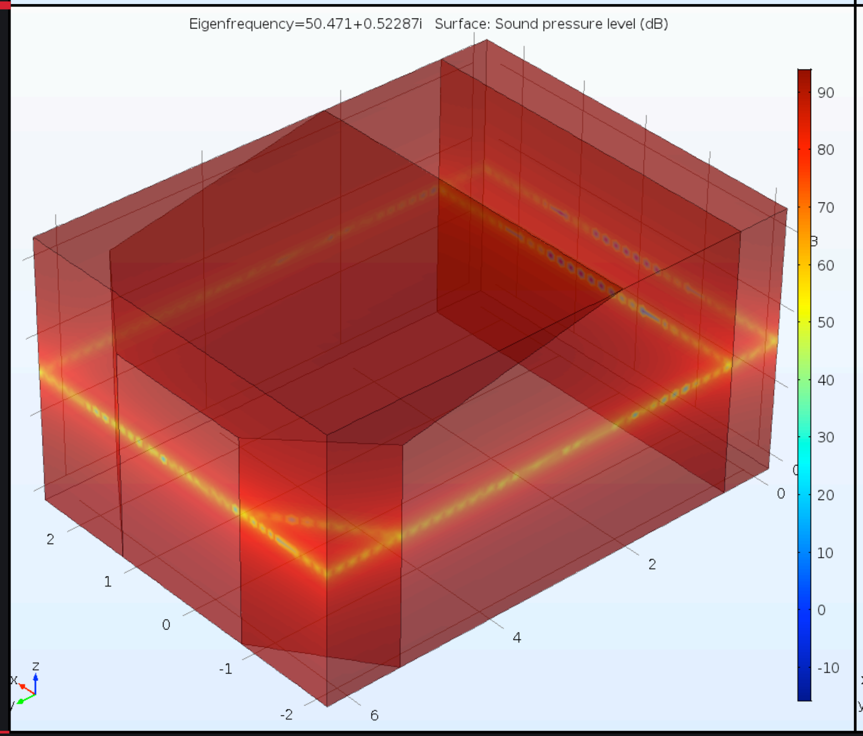
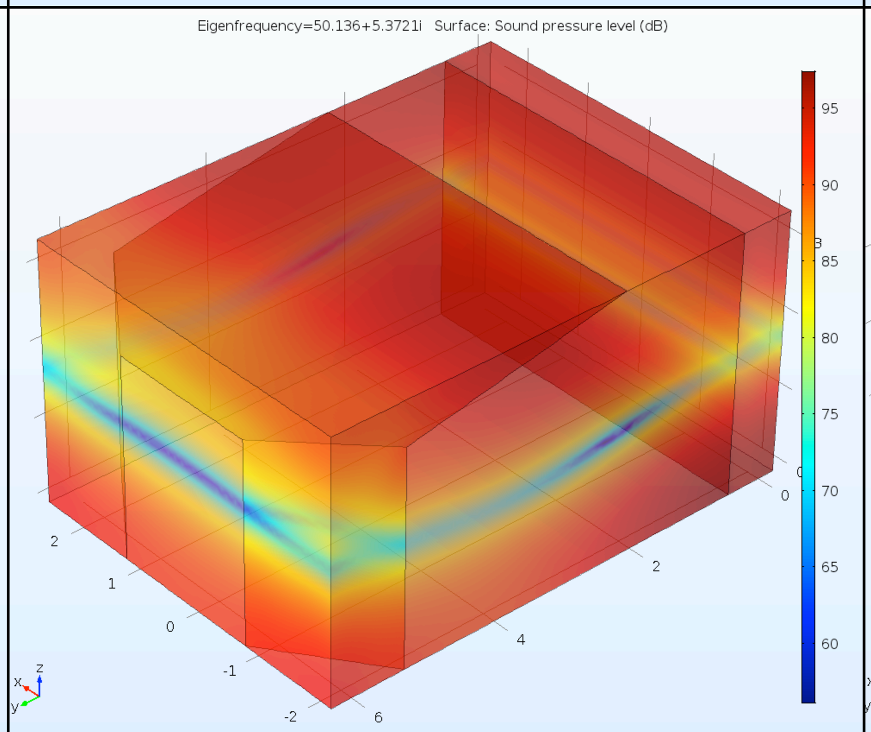
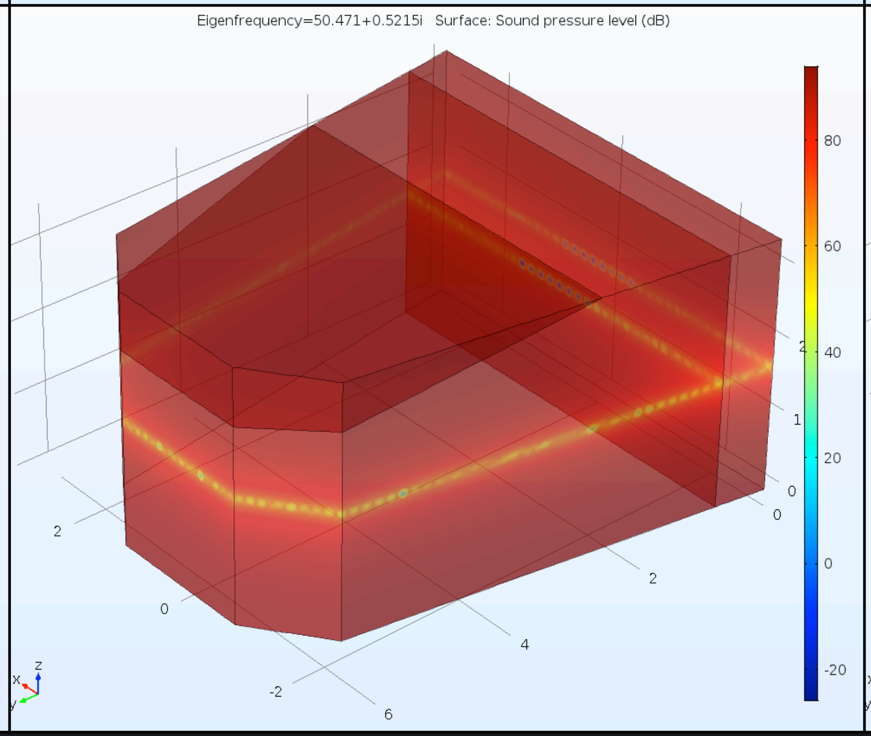
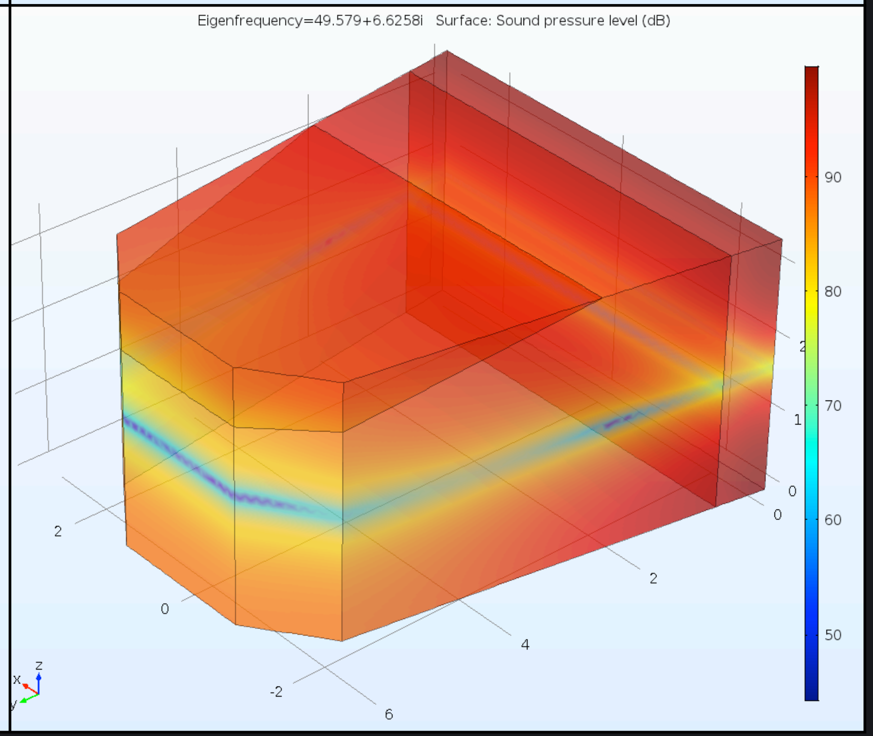
1L mode	Louden		Louden “slanted”	
Mode	f = 26.6 Hz not treated	f = 26.4 Hz treated	f = 27.3 Hz not treated	f = 26.9 Hz treated
MT60	MT60 = 2.44 s	MT60 = 0.38 s	MT60 = 2.48 s	MT60 = 0.52 s
Acoustic Pressure				
SPL				

Studio Sound Service

Donato Masci

“Optimal” rectangular room VS non rectangular one

Note the reduction of modal decay time in the treated cases and the frequency shift of the resonance frequencies, but the most interesting result is that, in the treated configurations, the sound pressure distribution is much more homogeneous.

1H mode	Louden		Louden “slanted”	
Mode	f = 50.5 Hz not treated	f = 50.1 Hz treated	f = 50.5 Hz not treated	f = 49.6 Hz treated
MT60	MT60 = 2.09 s	MT60 = 0.20 s	MT60 = 2.10 s	MT60 = 0.16 s
Acoustic Pressure				
SPL				

These are **some of the few modes** that you can recognise for the treated rooms.

In fact, even with this simple acoustic treatment, the modes completely degenerate and are destroyed above 50Hz, and then the sound pressure is distributed in an almost homogeneous way throughout the room.

You can notice:

A. the RT60 decrease in both treated cases

B. the modal frequency shift between untreated and treated *(so the room modes change!)*

D. a more homogeneous sound pressure distribution in the room for the treated cases

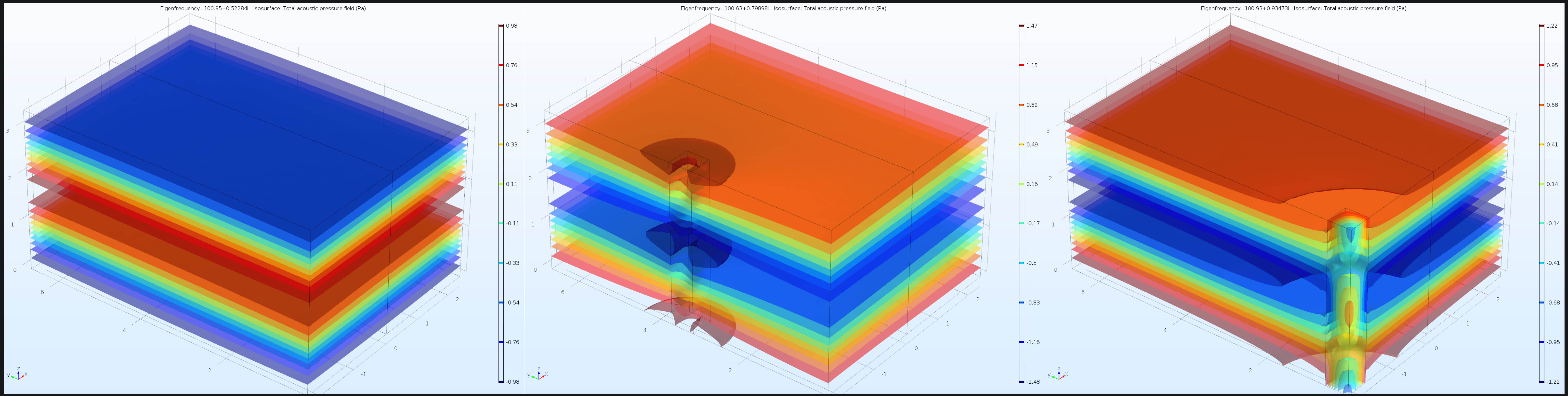
(and this is very useful for design purposes where it is necessary to minimise the effects of stationary waves and decreasing the discrepancy between the SPL in the maxima and minima in the room)

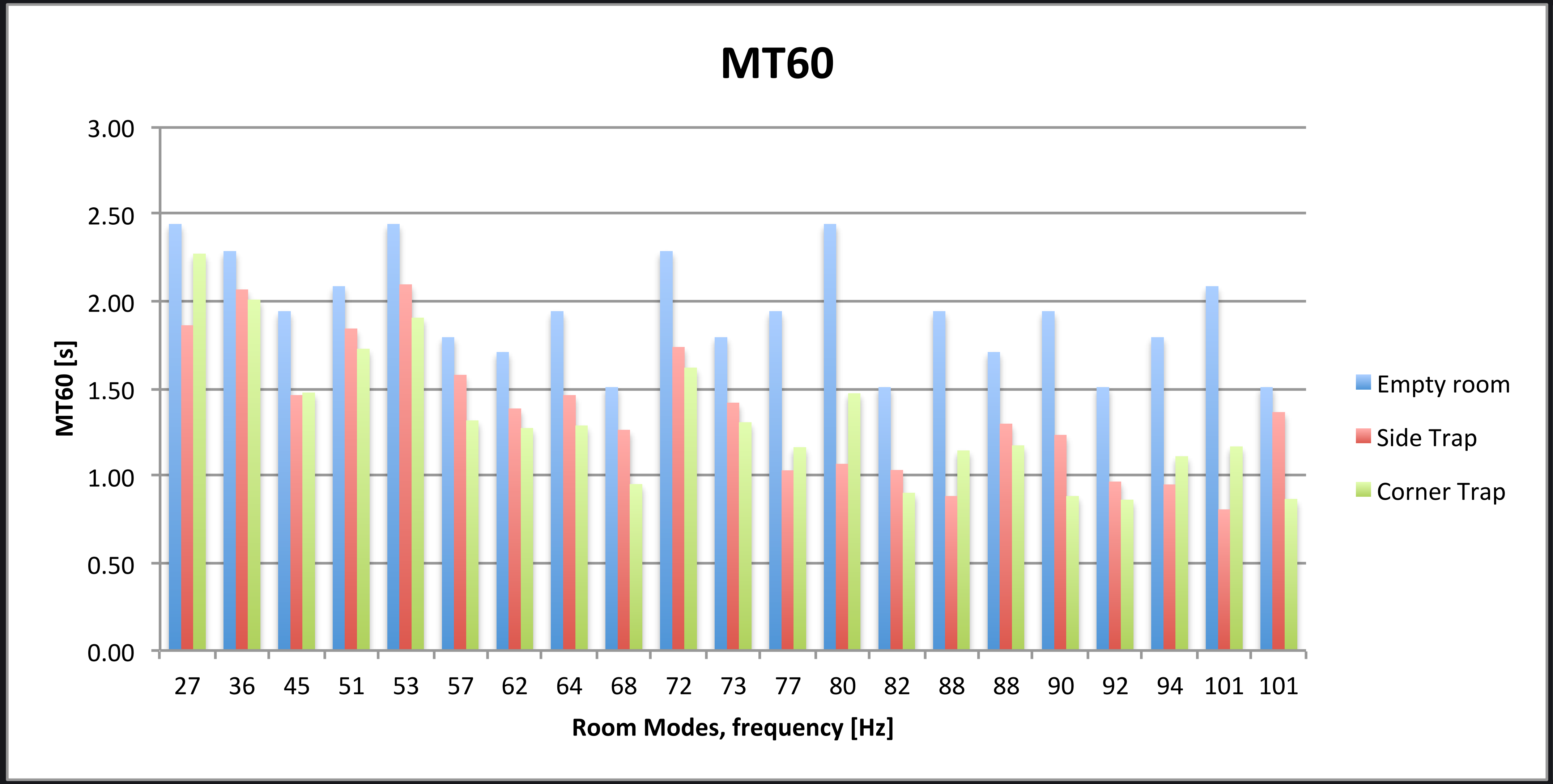
CASE 2.

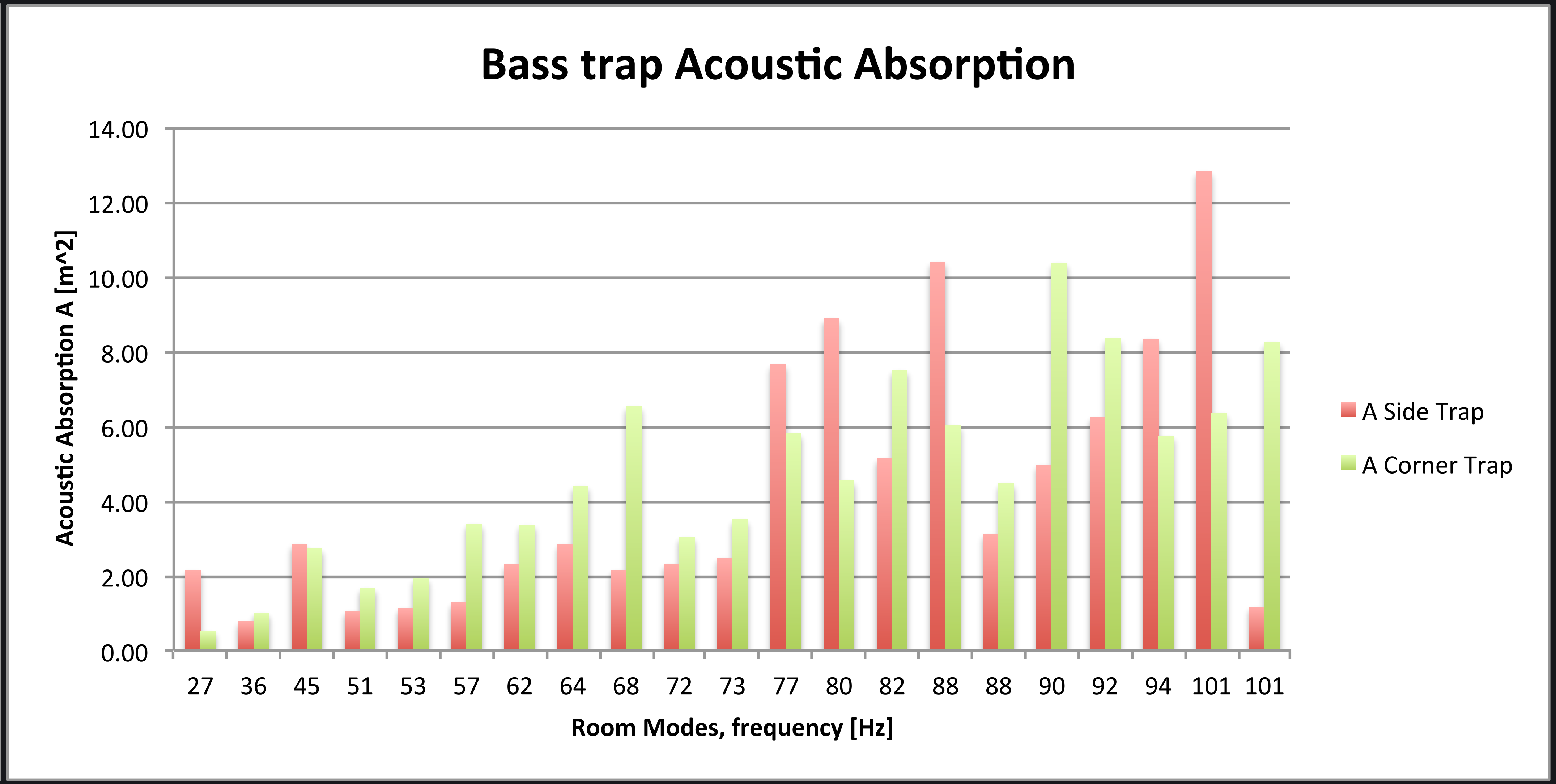
How the **reverberation time** changes in a room if you put an absorber on one side or in a corner?

Resonant modes in a room of an ideal size (Louden)

- first empty
- inserting an absorber of polyester fiber in the middle of the long side
- moving it to the corner

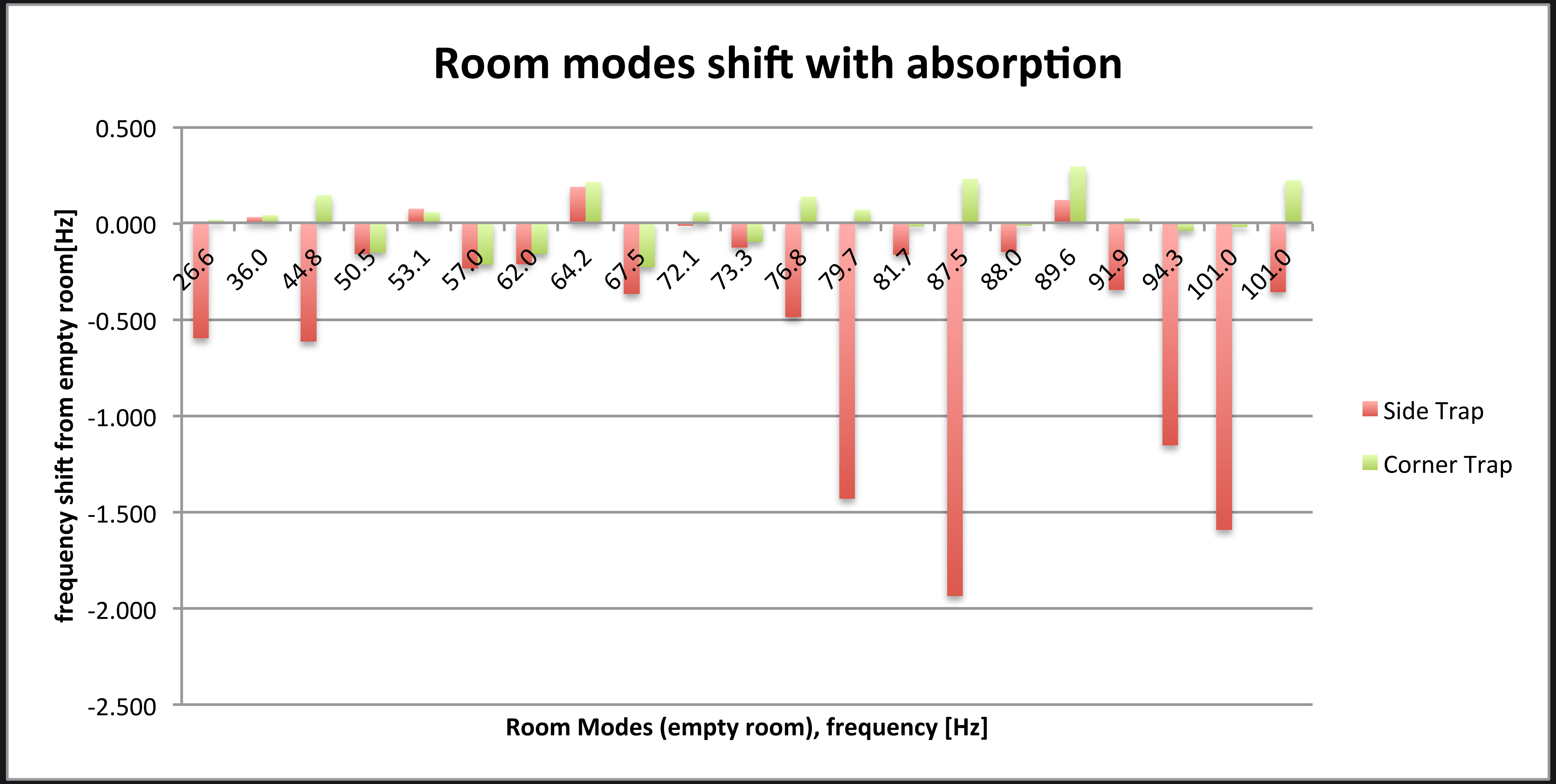






MT60 (modal decay time)
you can notice how the same bass trap works in very different ways in the two configurations, giving different decay times.

Absorption coefficient of the same bass trap in two configurations For some resonance modes (longitudinal and transverse axial), the side trap is very powerful, but in general the corner trap works better and more homogeneously over the whole spectrum.



resonant mode frequency shift between the side and the corner trap VS the untreated room

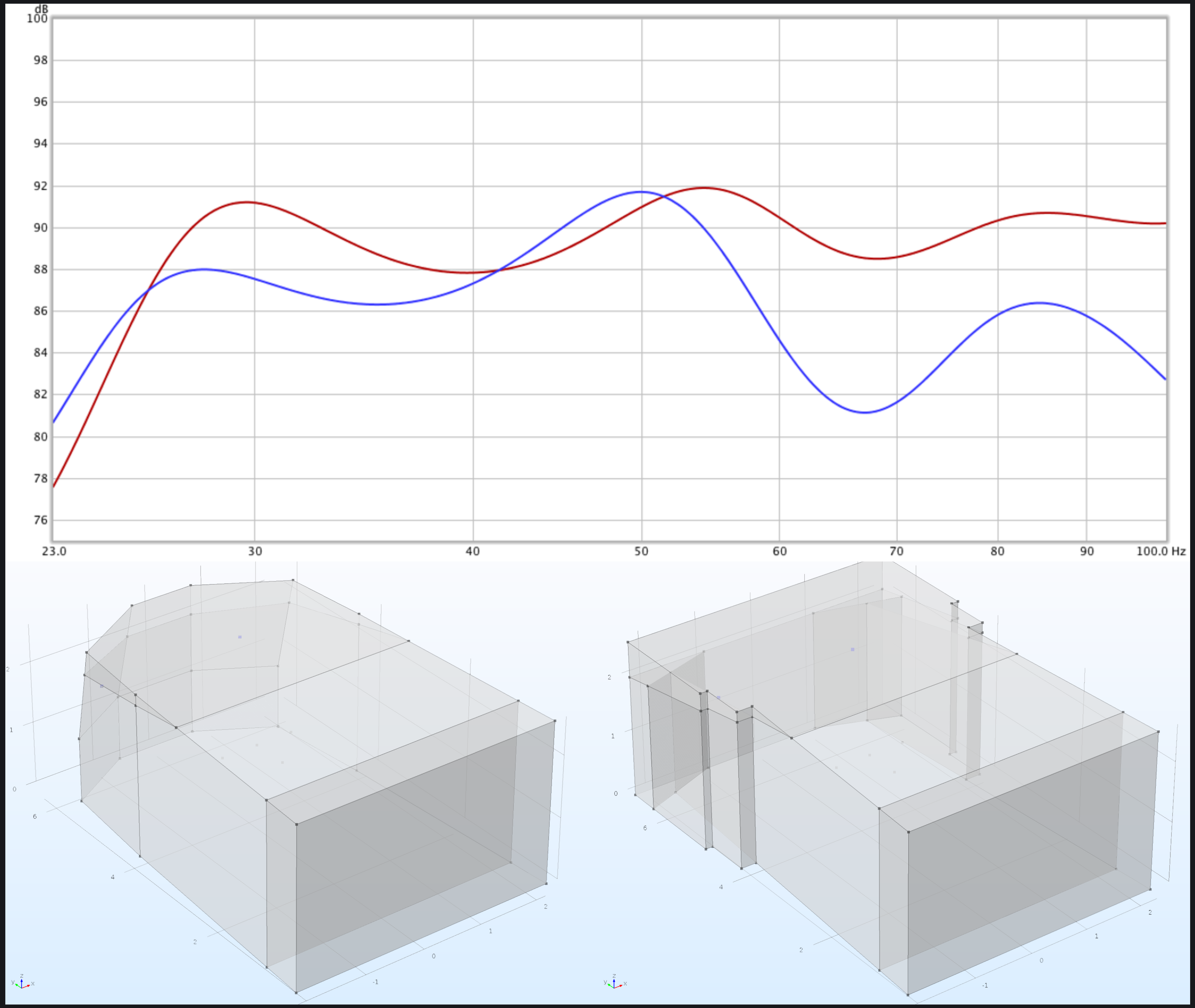
The room acoustic field is completely transformed even with the inclusion of a single bass trap

So, simulation is important, but optimisation is BETTER

CASE 3. Loudspeaker-boundary effect

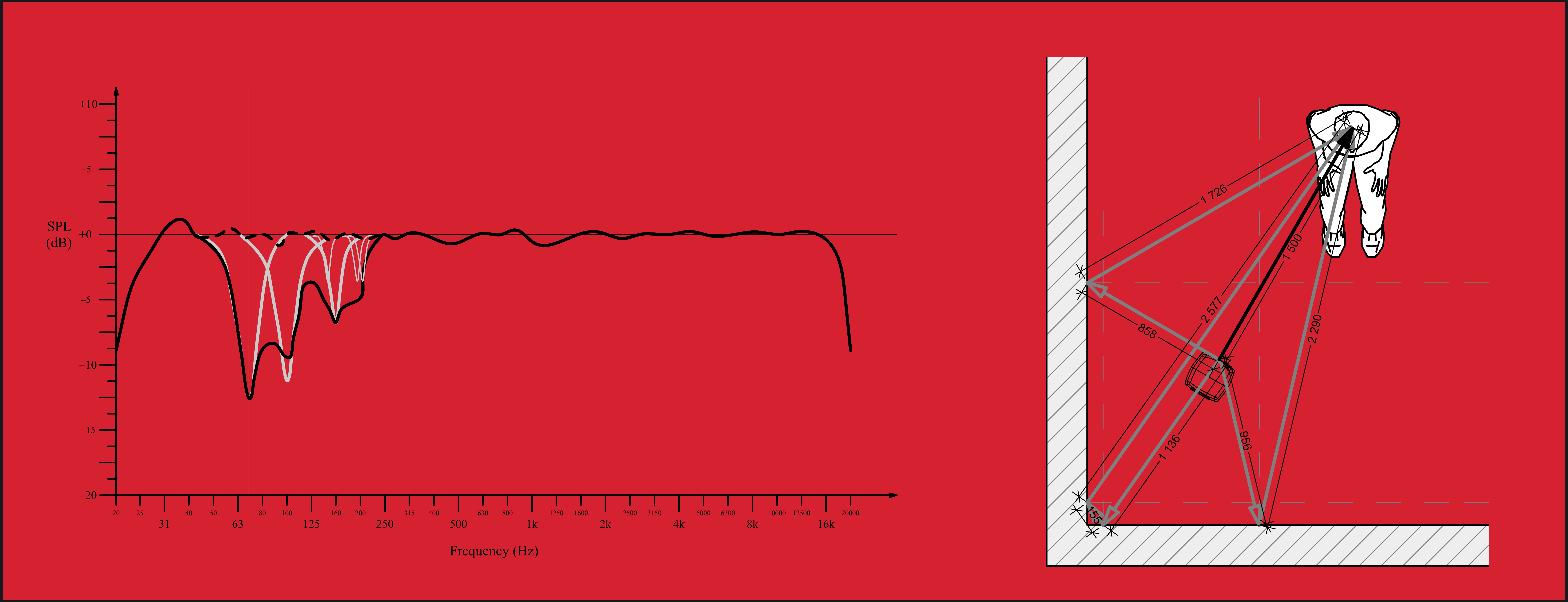
effects of ushmounting or not ushmounting the main monitors

Flush mount is an expensive way to place loudspeakers into a room. The best way to do it is using masonry or concrete.



FR of a flushmounted loudspeaker (red)
vs
non-flushmounted (blue)
in the same room
without acoustic treatment.

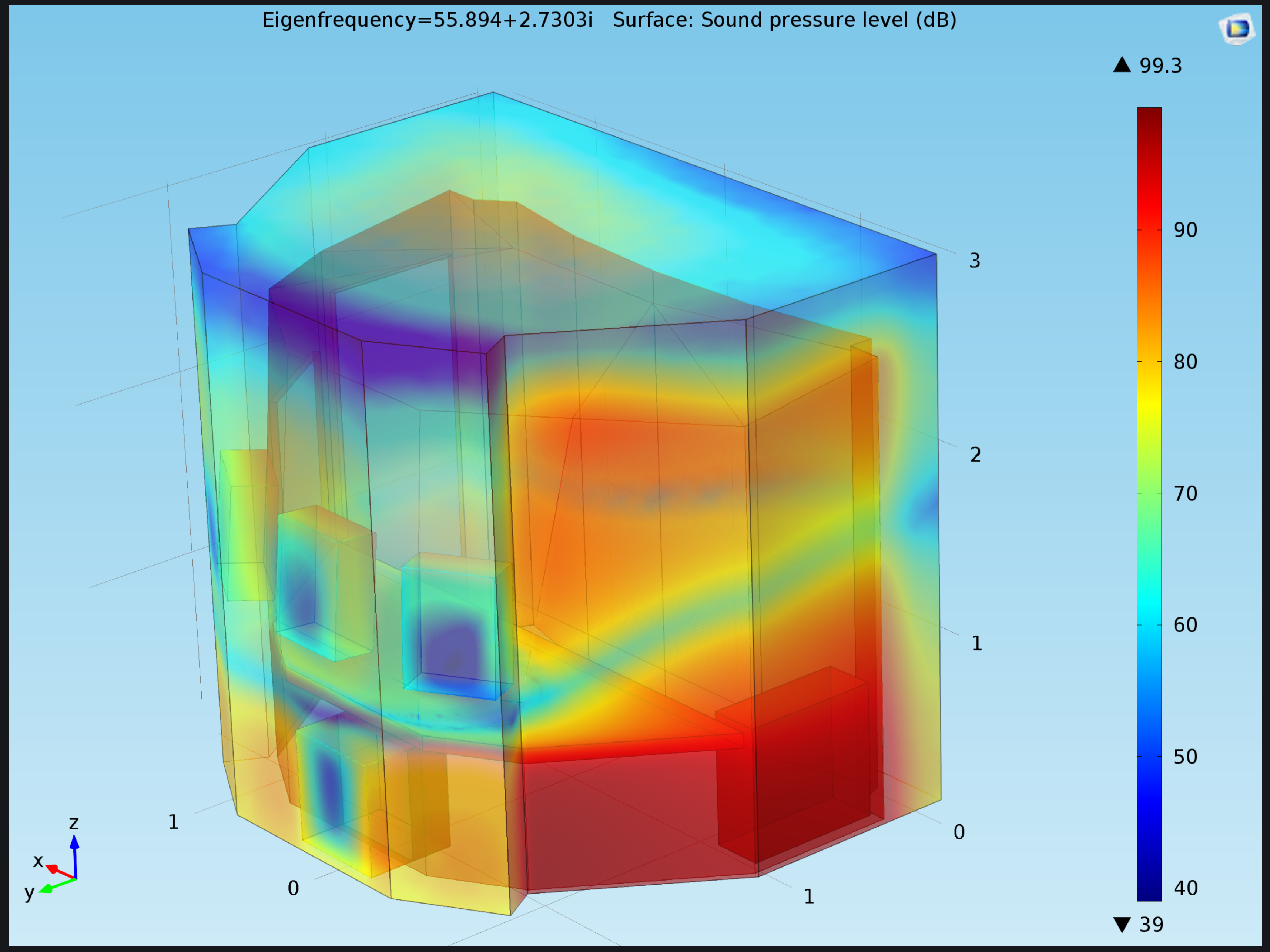
The difference is huge, the linearity is already sufficient for the flushmounted one.



You can finally see the non-minimum-phase effects caused by the loudspeaker-room interaction

Conclusions:

Is the FEM simulation useful for recording studio design?



A. FEM software is a **truly valuable tool for acoustic design**.
It provides considerable support to designers on a part of the spectrum range (**LF**) that we could not have much certainty on until now — unless you precisely adopt a predetermined design that you know works from trial-and-error.

B. The major innovation is that with these simulation methods you can build rooms with a good listening experience in **unconventional situations** while also studying **alternatives and innovative acoustic treatments**.

Problems:

is the FEM simulation/ optimisation usable **right now**? What are the main issue to solve and what can we improve?

A. **Impedance and Library:**

Comsol is a multiphysics simulation tool and it's not specific for acoustics – first thing to do is to build a **library** of **impedances** for most common partitions.

(An interesting method is developed by Roberto Magalotti, B&C Speakers starting from the IR measurement of the room)

Problems:

is the FEM simulation/ optimisation usable right now? What are the main issue to solve and what can we improve?

Table 3
Values of the eight coefficients in Eqs. (3)–(6) from the best-fit described in the present work for polyester fibre materials (NMI) compared with the values found by Delany–Bazley [5] and Dunn–Davern [6]

Model	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8
Delany–Bazley	0.057	0.754	0.087	0.732	0.189	0.595	0.098	0.700
Dunn–Davern	0.114	0.369	0.099	0.758	0.168	0.715	0.136	0.491
NMI	0.078	0.623	0.074	0.660	0.159	0.571	0.121	0.530

NMI is Garai-Pompoli

B. Porous material:

many times, using the Delany-Bazley or other coefficients to simulate the poroacoustics the simulation did not converge.

For polyester fibre materials I used the coefficients found in the article of Massimo Garai and Francesco Pompoli "A simple empirical model of polyester fibre materials for acoustical applications" – with this model the porous absorption is really well simulable and optimisable.

Problems:

LF source? woofer, bass reflex?
using loudspeaker acoustic axis?

Genelec 1036A

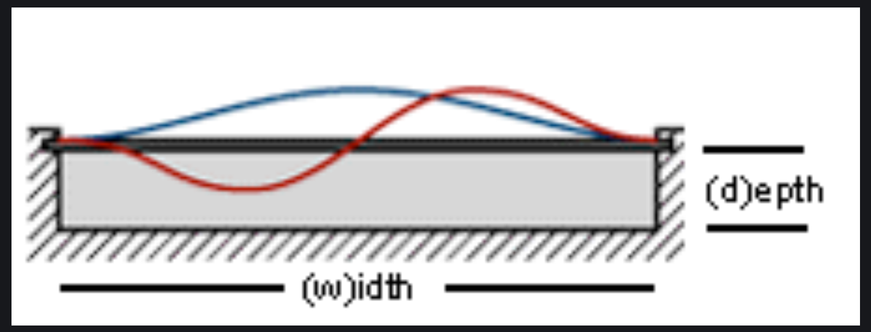
C. Loudspeakers LF as source:

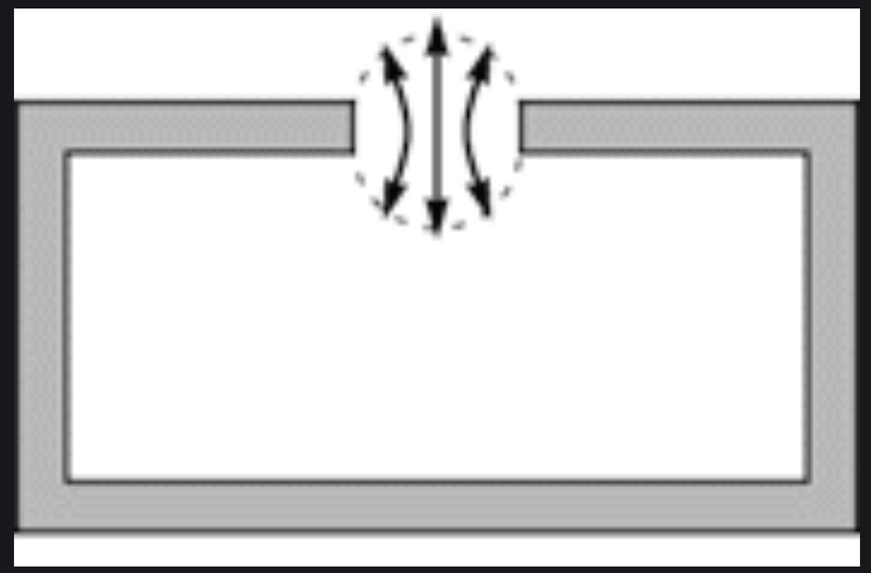
what is the best point to place the sound source?
- the woofer? (which one?!)
- bass reflex?
- loudspeaker's acoustic axis?

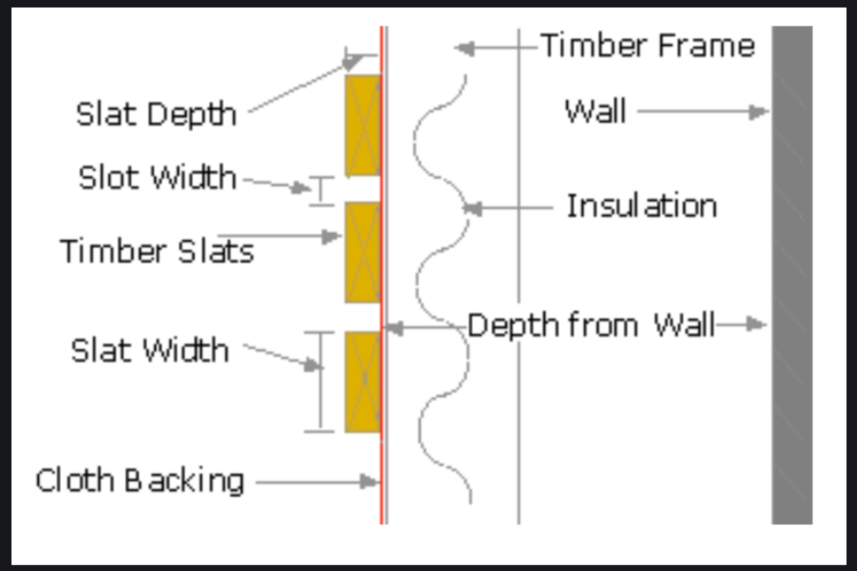
Even if room modes are not so modified by a 50 cm difference, the main issues come from loudspeaker-boundary interaction (phase cancellations, comb filters).

Problems:

Membrane absorbers for a thinner treatment instead of porous materials.







D. Resonant systems:

resonant systems, such as membrane, panel or Helmholtz absorbers – I would like to understand even better how to simulate them with COMSOL and how to optimise them to use them in a recording studio design.

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Thank you

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