NAS Høstmøte 2019, Trondheim

Multiconsult

På jakt etter det musikalske øvingsrommet

(Search for the musical rehearsal room)

Jens Holger Rindel

Multiconsult, Oslo, Norway

Abstract

- The dimensions of small rooms are important for the frequency distribution of the room modes.
- Different criteria can be applied to evaluate whether the frequency distribution is favourable; a smooth frequency response, the variance of the interval between modal frequencies, or the number of tones in the musical scale, supported by at least one of the room modes.
- The ananlysis leads to a practical method for choosing favourable room dimensions in a music room.

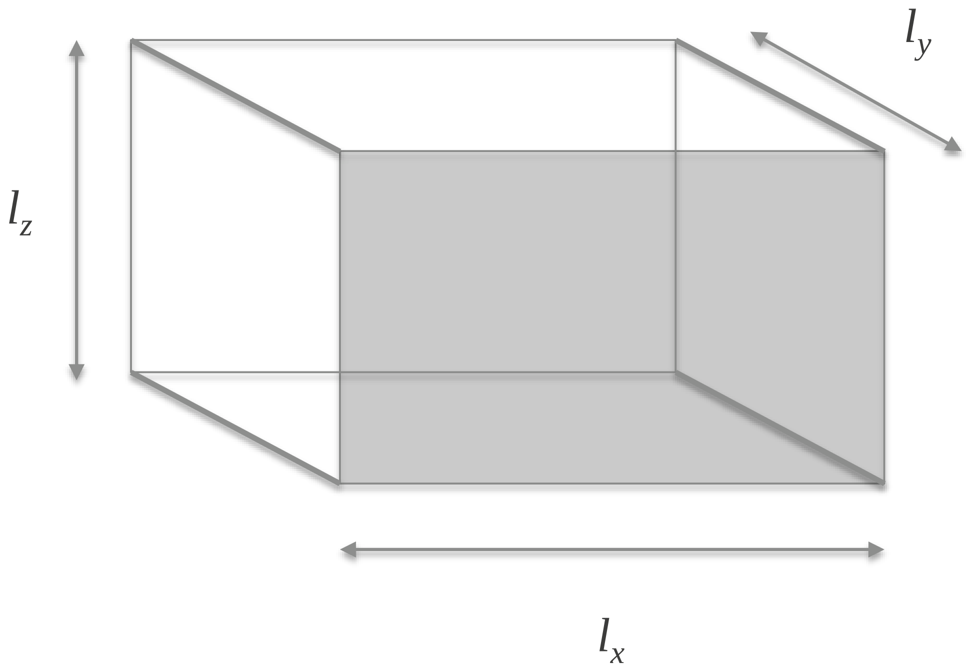
Outline

- Normal modes in a rectangular room
- Analysis of smoothness of frequency response
- Analysis of musical tones supported by room modes
- Analysis of frequency spacing between room modes
- Suggested method for choosing room dimensions

Objective criteria for the goodness of a room

- The analysis is restricted to:
  - small room volumes (up to 300 m^3)
  - low frequencies (up to 220 Hz)
  - box-shaped rooms, in which the normal modes can easily be calculated
- The criteria considered are:
  - Smoothness of the global transfer function
  - Number of musical tones supported by the room modes
  - Distribution function for the separation between room modes

Normal modes of a rectangular room



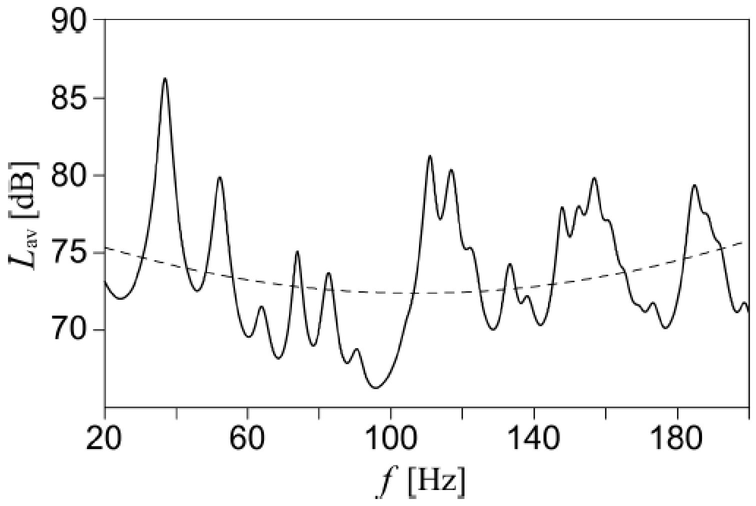
Dimension ratio:

$$1 : \frac{l_y}{l_z} : \frac{l_x}{l_z} = 1 : \frac{W}{H} : \frac{L}{H}$$

Natural frequency of mode (n_x, n_y, n_z):

$$f_n = \frac{c}{2}\sqrt{\left(\frac{n_x}{l_x}\right)^2 + \left(\frac{n_y}{l_y}\right)^2 + \left(\frac{n_z}{l_z}\right)^2}$$

Frequency response - Meissner (2018)

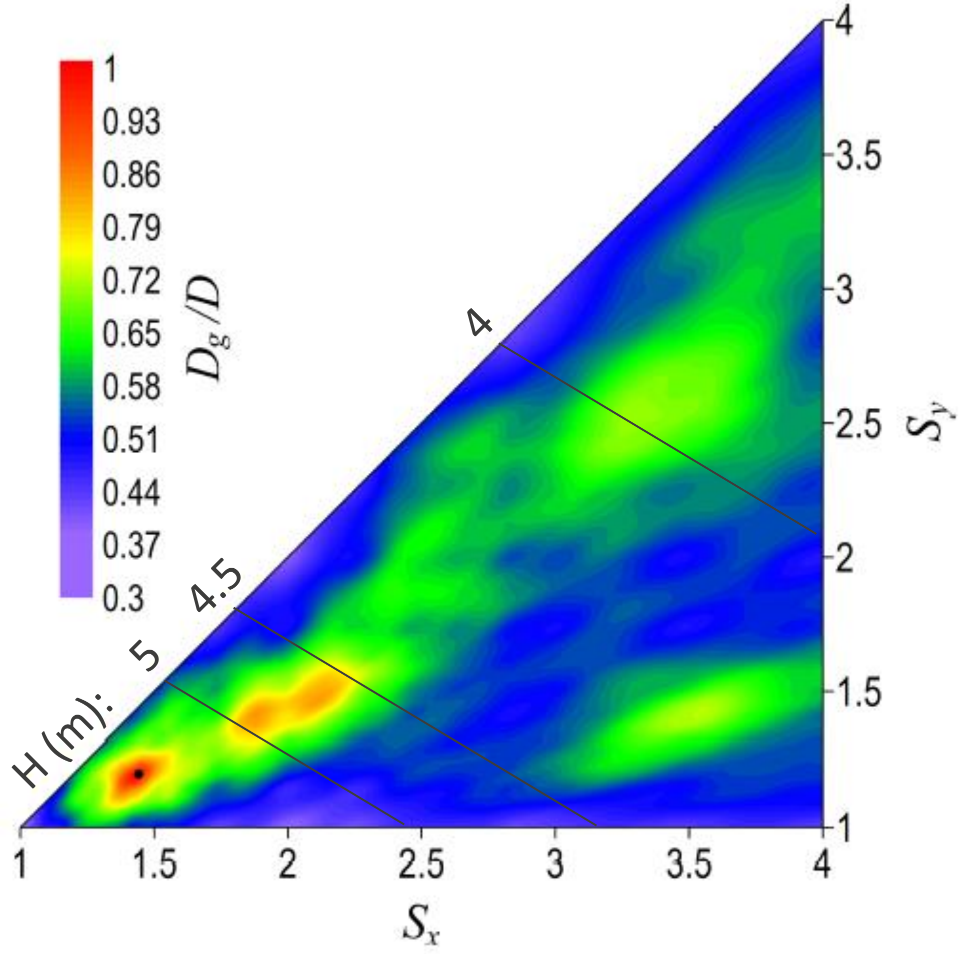


- Looked at the global frequency response curve from 20 Hz to 200 Hz
- Criterion: The curve should be as smooth as possible
- Method: Calculate the correlation coefficient for a 2nd order polynomial.
- The correlation should be as high as possible
- NB: Result depends on the absorption of the surfaces and volume

300 m³ – Meissner (2018) Fig. 6

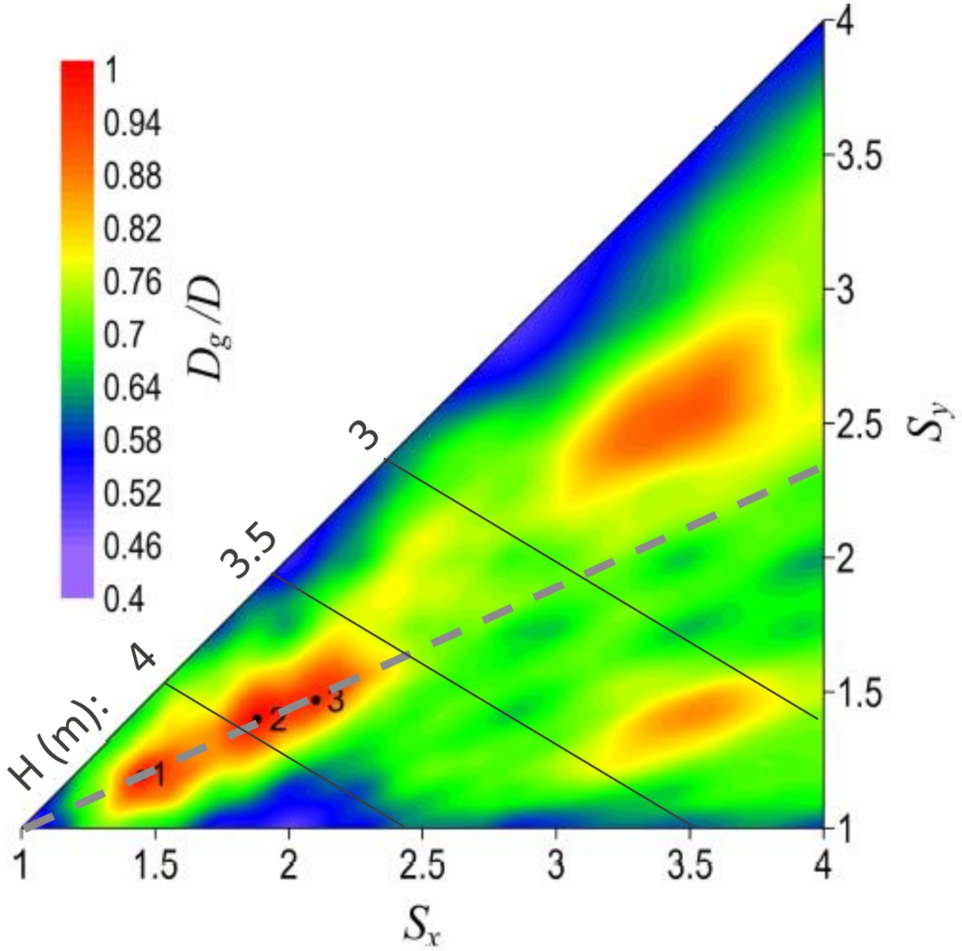
S_x = L/H
S_y = W/H

Optimum ratio:
1 : 1.2 : 1.45



150 m³ – Meissner (2018) Fig. 8

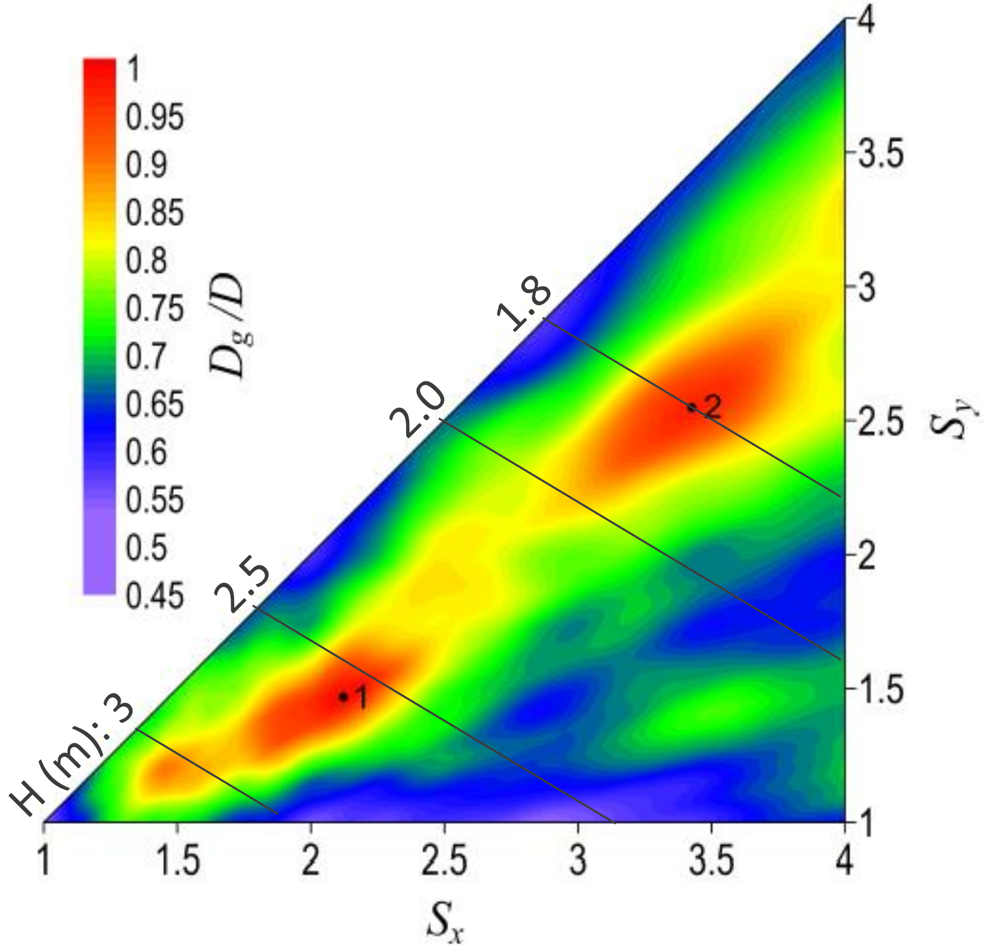
Optimum ratios:
1 : 1.2 : 1.45
1 : 1.4 : 1.89
1 : 1.47 : 2.1



50 m³ – Meissner (2018) Fig. 7

Optimum ratios:
1 : 1.47 : 2.12
(1 : 2.55 : 3.44)

NB: The upper part of diagram is not usable due to unrealistic low Room height

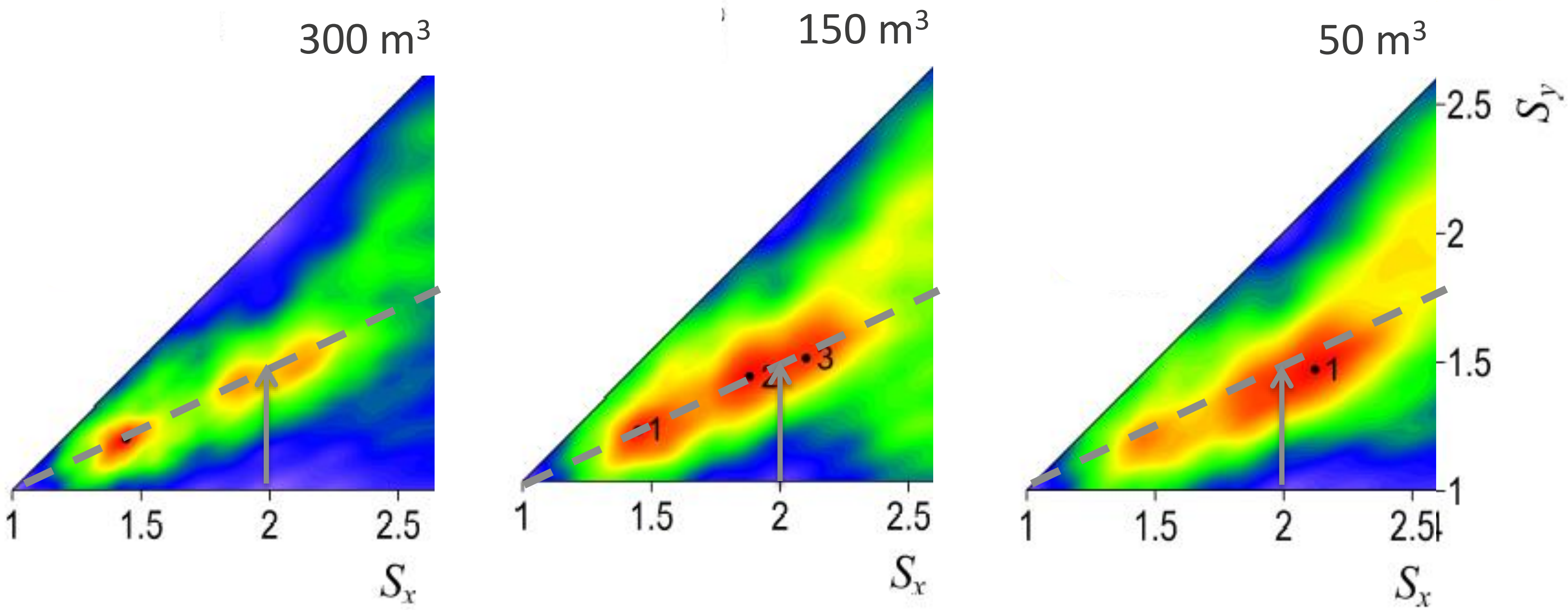


Nearly optimum range

For usable room heights, the optima are located on a line.

Sx = L/H = 2: This is not bad, although often warned against!

The often recommended ratio 1 : 1.25 : 1.6 is not good!



Optimum dimension ratios from Meissner (2018)

Dimension ratios that are found to produce very smooth transfer functions:

A: 1 : 1.2 : 1.45
B: 1 : 1.4 : 1.89
C: 1 : 1.48 : 2.12

Regression line is:

$$L/H = 2.36 \cdot W/H - 1.38$$

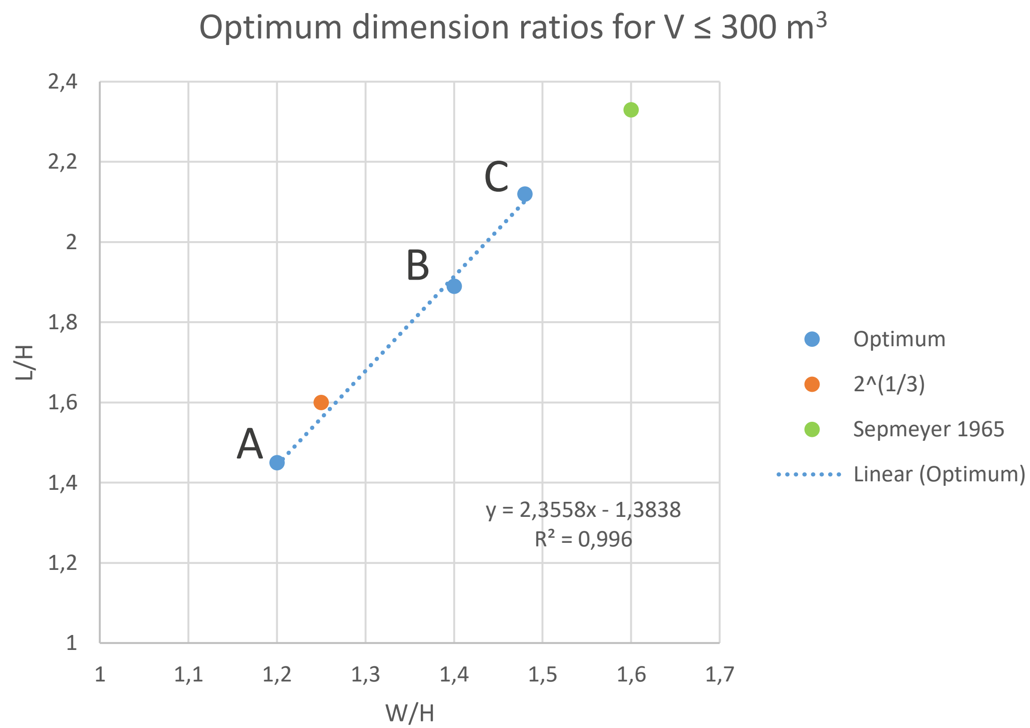
where

L is room length,

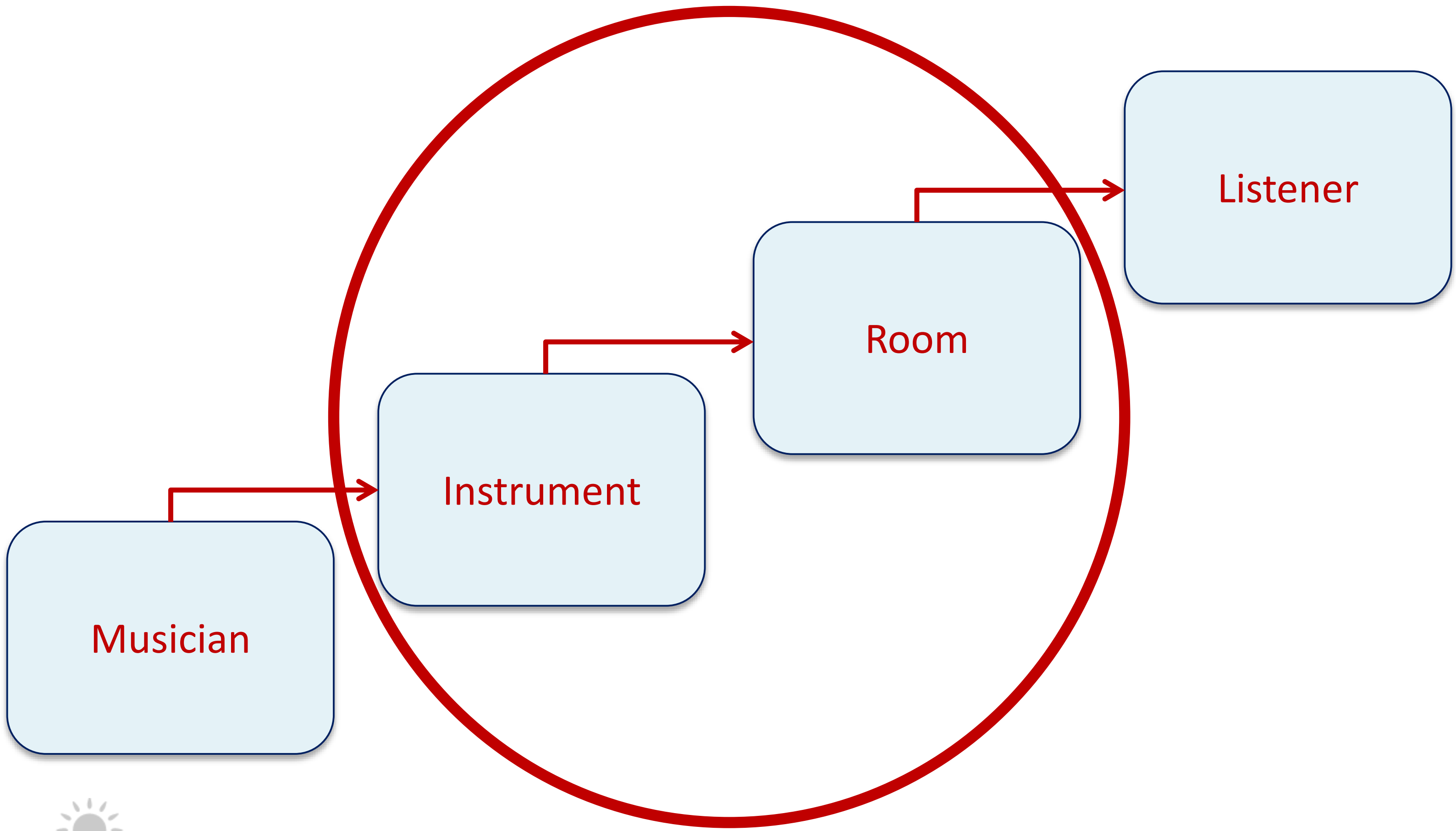
W is room width

H is room height.

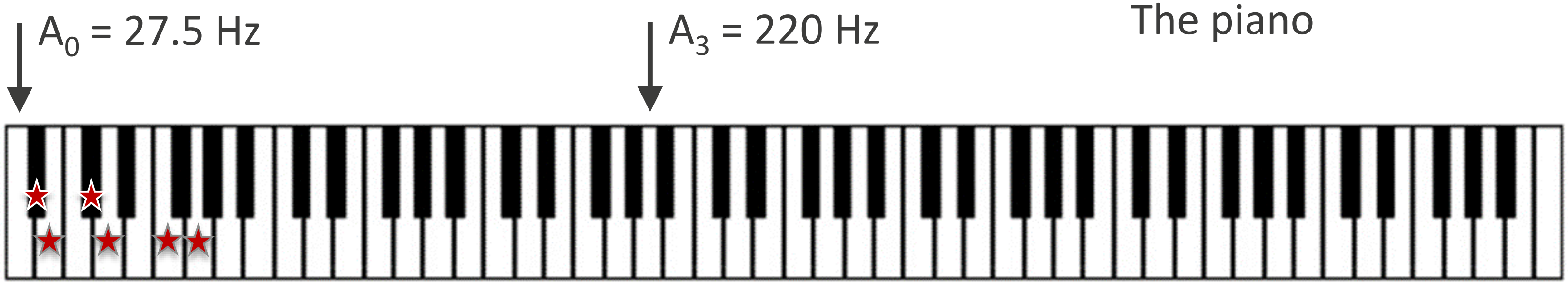
The ratio *W/H* should be within the range 1.2 to 1.6.

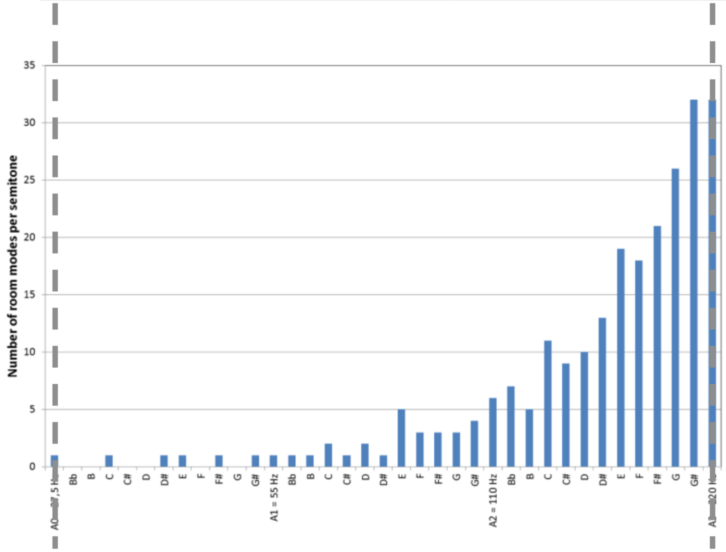


The room as extension to a musical instrument



The room as extension to a musical instrument



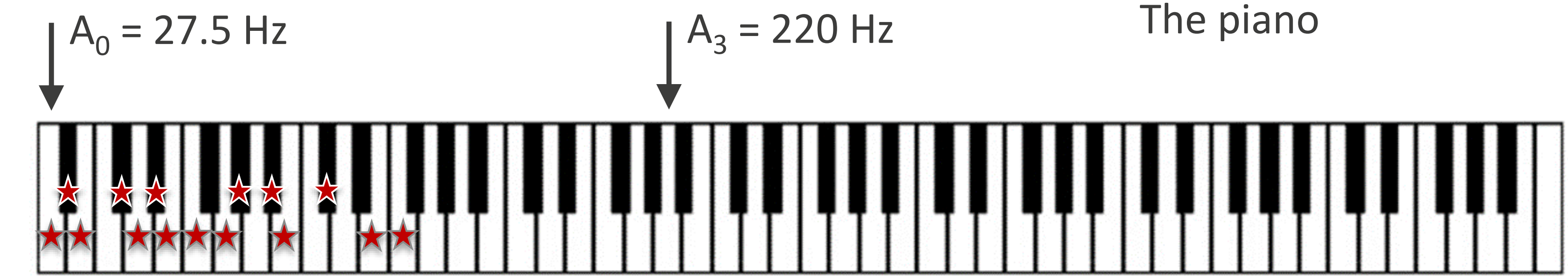


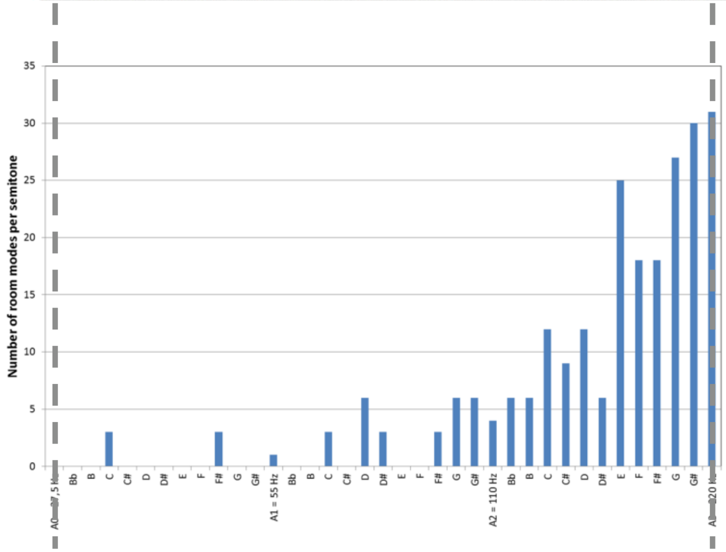
Example:
150 m^3 room with
optimum dimensions (A)

31/37 tones are matched with one or more room modes

6 tones are not well supported by the room ★

The room as extension to a musical instrument





Example:
150 m^3 room with
dimension ratio 1:1:1

22/37 tones are matched with one or more room modes

15 tones are not well supported by the room ★

22/37 tones

150 m³ rooms – Number of tones in 3 octaves

Number of tones within the range A0 = 27,5 Hz to A3 = 220 Hz (Max 37)

L/H

1	1.05	1.1	1.15	1.2	1.25	1.3	1.35	1.4	1.45	1.5	1.55	1.6	1.65	1.7	1.75	1.8	1.85	1.9	1.95	2	2.05	2.1	2.15	2.2	W/H
22	25	26	27	28	27	27	25	25	25	26	25	26	25	25	24	26	28	27	23	23	23	26	26	25	1
	24	29	29	30	28	30	30	29	28	27	28	28	28	28	28	26	27	29	27	27	27	25	28	28	1.05
		27	27	30	30	28	29	30	29	29	29	29	28	28	28	28	29	28	29	27	28	28	28	27	1.1
			26	30	31	30	30	31	28	29	29	29	29	28	28	28	28	29	29	26	28	28	28	27	1.15
				27	31	30	31	31	31	29	29	28	28	28	28	28	28	29	29	28	29	28	28	28	1.2
					28	29	29	30	31	29	28	28	27	27	27	28	29	29	28	28	29	29	28	28	1.25
						25	27	30	30	30	28	28	27	27	28	28	29	30	28	27	28	30	28	28	1.3
							26	27	29	30	28	27	28	29	28	28	29	29	29	27	28	30	30	28	1.35
								25	29	30	30	28	28	28	28	29	30	29	28	28	29	30	30	30	1.4
									25	30	31	30	28	28	29	29	29	28	28	28	28	30	30	30	1.45
										27	29	30	28	27	28	29	28	28	27	28	28	29	30	30	1.5
											27	28	29	27	28	28	30	28	27	28	28	30	30	29	1.55
												27	28	28	28	28	29	28	29	28	29	29	29	28	1.6
													27	28	28	28	28	28	26	26	27	29	29	29	1.65
														27	28	28	28	27	26	26	26	27	28	28	1.7
															26	28	28	28	27	26	27	27	27	28	1.75
																26	28	28	27	27	27	27	28	27	1.8
																	26	27	28	27	27	28	28	28	1.85
																		26	26	27	28	28	28	28	1.9
																			25	24	26	26	27	28	1.95
																				24	24	26	26	26	2

A, B and C:
Optima from
Meissner (2018)

Curve for nearly optimum dimension ratios

50 m³ – Number of tones in 3 octaves

Number of tones within the range A0 = 27,5 Hz to A3 = 220 Hz (Max 37)

L/H

1	1.05	1.1	1.15	1.2	1.25	1.3	1.35	1.4	1.45	1.5	1.55	1.6	1.65	1.7	1.75	1.8	1.85	1.9	1.95	2	W/H
16	17	20	20	19	20	21	21	20	20	21	21	21	21	20	20	21	21	21	17	17	1
	18	22	22	20	23	24	24	22	23	23	23	23	23	21	22	23	22	22	22	19	1.05
		19	24	24	23	23	24	24	23	24	23	24	23	23	23	23	23	22	21	21	1.1
			20	22	22	23	24	24	24	23	24	25	23	23	24	24	24	21	20	20	1.15
				21	21	22	22	23	A	24	24	24	23	23	23	24	23	23	21	20	1.2
					21	23	23	24	23	24	23	23	23	23	23	24	25	25	23	22	1.25
						21	23	23	24	22	24	23	25	25	24	22	24	25	24	23	1.3
							19	23	23	24	22	23	25	25	25	25	25	23	22	23	1.35
								18	20	23	24	24	23	23	23	25	25	B	23	22	1.4
									19	21	24	24	24	23	23	24	24	25	25	22	1.45
										20	24	24	24	22	22	24	25	25	24	23	1.5
											20	23	24	24	24	24	24	25	23	23	1.55
												20	22	23	24	24	23	23	23	23	1.6
													18	19	22	23	23	23	23	23	1.65
														19	19	21	23	23	21	22	1.7
															19	19	22	22	23	22	1.75
																19	22	22	22	21	1.8
																	19	22	21	21	1.85
																		18	20	21	1.9
																			18	18	1.95
																				18	2

Room height

3.0 m

2.7 m

2.5 m

A and B:
Optima from
Meissner (2018)

Curve for nearly optimum dimension ratios

30 m^3 – Number of tones in 3 octaves

Number of tones within the range A0 = 27,5 Hz to A3 = 220 Hz (Max 37)

W/H \ L/H	1	1.05	1.1	1.15	1.2	1.25	1.3	1.35	1.4	1.45	1.5	1.55	1.6	1.65	1.7	1.75	1.8	1.85	1.9	1.95	2
1	13	14	17	17	16	18	17	18	17	17	18	18	18	18	17	17	19	18	18	14	14
1.05		16	18	19	18	20	21	21	20	20	20	20	20	20	19	20	20	20	19	19	16
1.1			16	21	21	20	20	21	21	21	21	20	20	20	20	20	20	20	19	19	18
1.15				18	19	20	20	21	20	22	21	20	21	21	18	21	21	21	18	17	17
1.2					18	18	20	19	21	20	20	21	21	20	20	19	20	20	20	18	17
1.25						18	20	20	22	20	21	20	20	20	20	19	21	22	22	20	19
1.3							18	20	20	21	19	21	20	21	21	20	20	22	22	22	20
1.35								16	20	20	20	20	20	21	22	20	22	22	20	21	20
1.4									15	17	20	21	21	19	20	21	22	22	22	20	20
1.45										16	18	21	21	20	21	21	22	22	22	22	19
1.5											17	21	21	21	21	20	21	22	22	21	20
1.55												17	21	21	21	21	21	21	22	22	20
1.6													18	19	20	21	21	21	21	20	20
1.65														15	15	19	20	20	20	20	20
1.7															16	16	20	20	20	19	19
1.75																16	16	19	20	20	18
1.8																	16	19	19	19	19
1.85																		16	19	19	18
1.9																			16	17	18
1.95																				15	15
2																					15

Room height

2.5 m

2.3 m

A

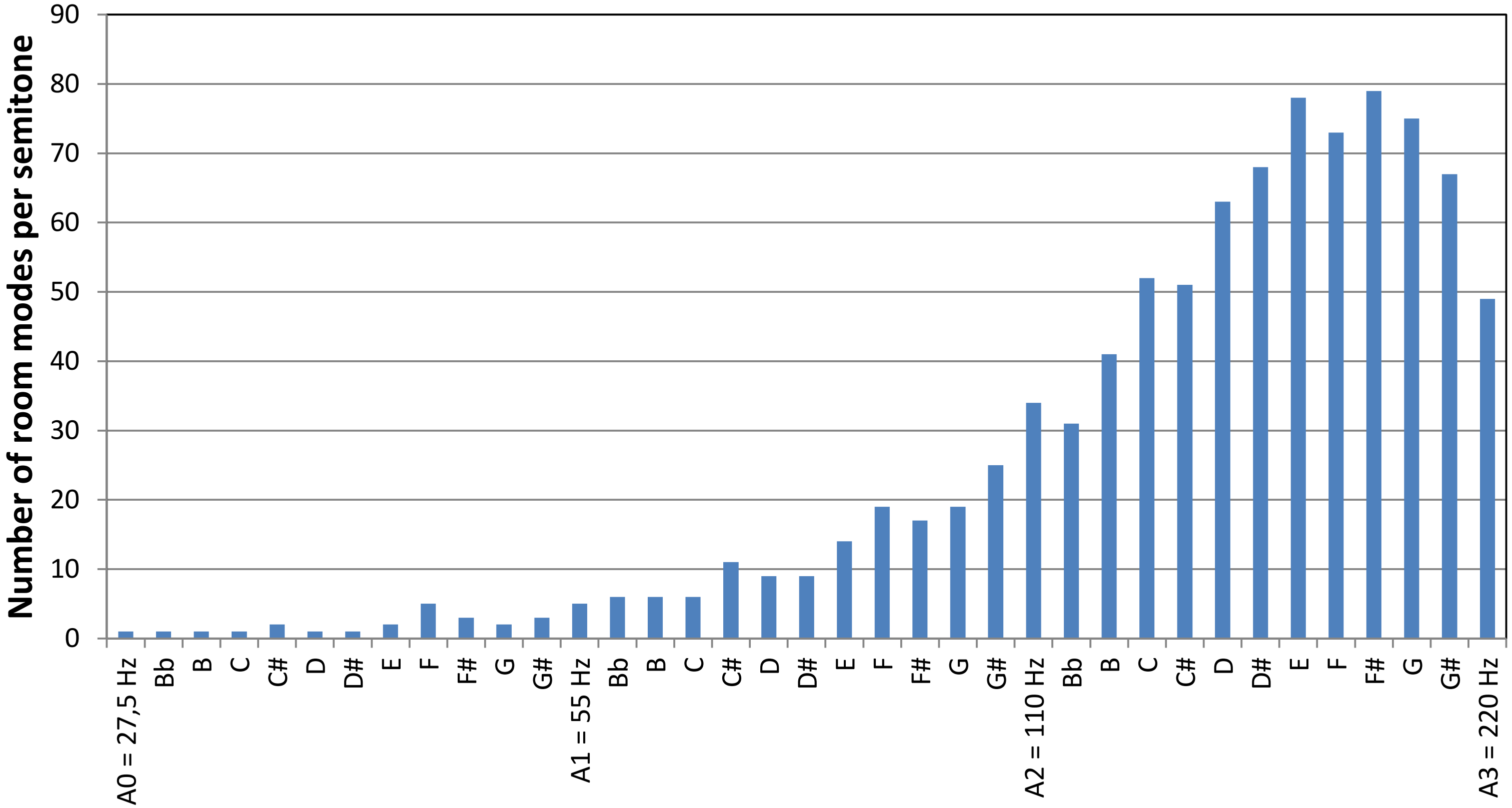
B

A and B:
Optima from
Meissner (2018)

Curve for nearly optimum dimension ratios

Minimum volume for full coverage

V = 1000 m^3 and room dimension ratio A: 1 : 1.2 : 1.45



Frequency Spacing Index ψ

1 : 1.2 : 1.45 (150 m³)

n_x	n_y	n_z	f_n [Hz]	δ
1	0	0	26.8	
0	1	0	32.4	5.6
0	0	1	38.9	6.5
1	1	0	42.0	3.2
1	0	1	47.2	5.2
0	1	1	50.6	3.4
2	0	0	53.6	3.0
1	1	1	57.2	3.6
2	1	0	62.6	5.4
0	2	0	64.8	2.1
2	0	1	66.2	1.4
1	2	0	70.1	3.9
2	1	1	73.7	3.6
0	2	1	75.5	1.8
0	0	2	77.7	2.2
1	2	1	80.1	2.4
3	0	0	80.4	0.3
1	0	2	82.2	1.8
2	2	0	84.1	1.9
0	1	2	84.2	0.1
3	1	0	86.7	2.5
1	1	2	88.4	1.7
3	0	1	89.3	0.9
2	2	1	92.6	3.3
2	0	2	94.4	1.8

Definition:

$$\psi\,(n) = \frac{1}{f_n - f_1} \cdot \sum_{1}^{n-1} \left(\frac{\delta^2}{\bar{\delta}} \right)$$

Where n is the number of modes considered, δ is the frequency difference between one mode and the next.

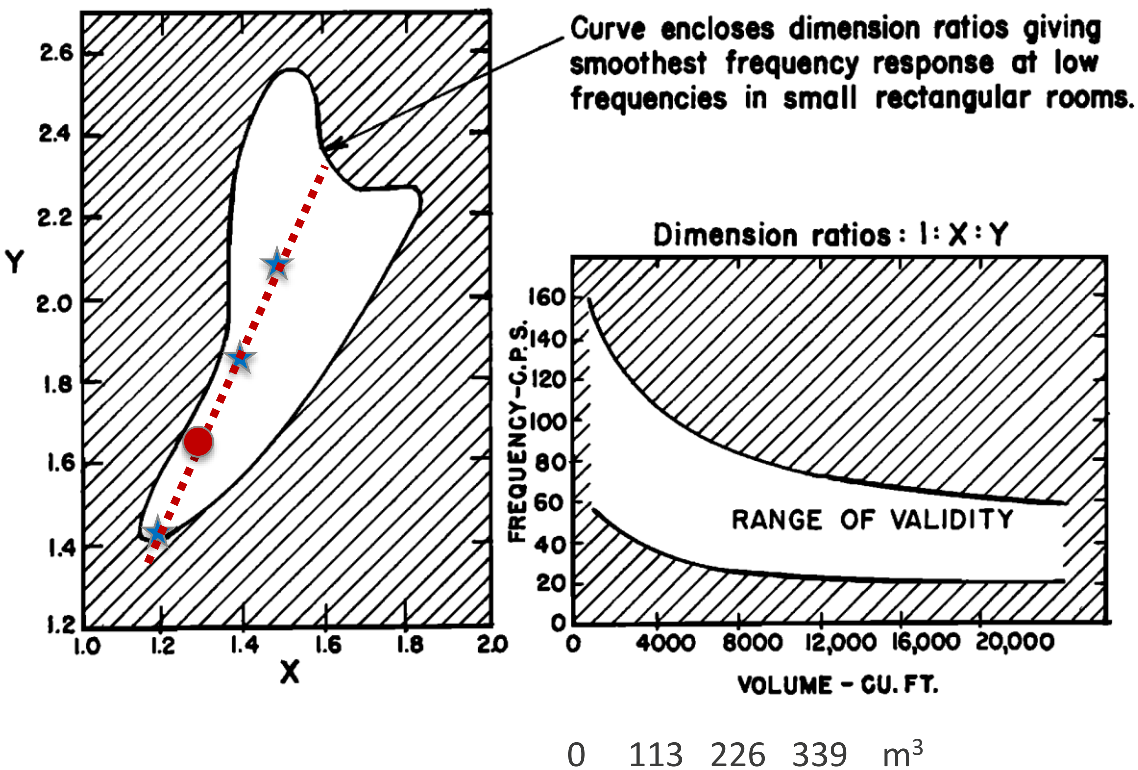
The average frequency spacing is $\bar{\delta} = \frac{f_n - f_1}{n - 1}$

RMS frequency spacing is: $\delta_{rms} = \sqrt{\psi\,\bar{\delta}}$

Ψ = 1 is ideal

Ψ = 3.5 is worst case (a cubic room)

Bolt (1946)



★ Optima suggested by Meissner (2018)

- Contour for frequency spacing index $\psi_1 < 1.5$.

  Problematic to include the ratio $Y = 2$

  The frequency validity range does not include the lowest room modes

  The findings by Meissner (2018) are within the suggested range

Frequency Spacing Index ψ of first 25 room modes

Frequency spacing index ψ(25)

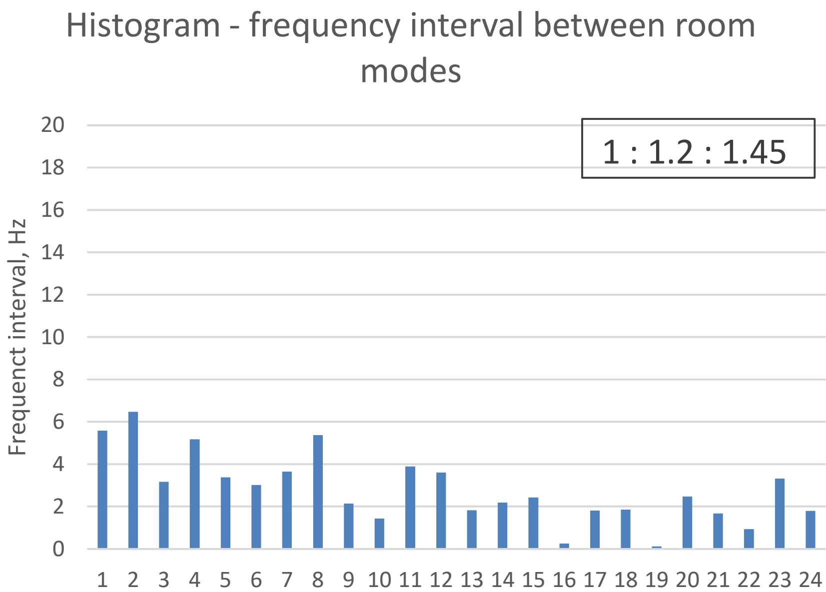
L/H

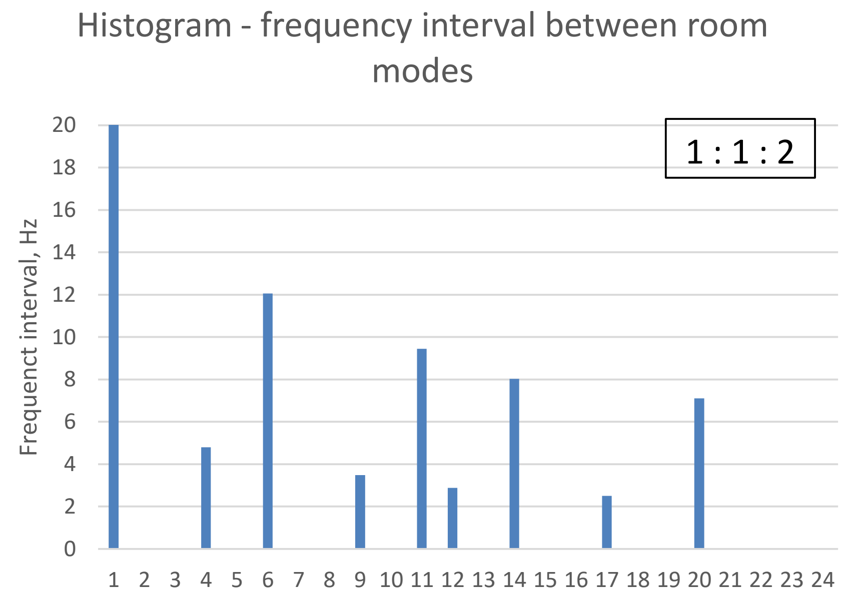
1	1.05	1.1	1.15	1.2	1.25	1.3	1.35	1.4	1.45	1.5	1.55	1.6	1.65	1.7	1.75	1.8	1.85	1.9	1.95	2	2.05	2.1	2.15	2.2	W/H
3.7	2.8	2.4	2.4	2.2	2.2	2.1	2.1	2.4	2.4	2.5	2.6	2.7	2.9	3.0	3.1	3.0	3.0	3.1	3.4	3.9	3.5	3.2	3.1	3.0	1
	2.7	2.0	1.9	1.8	1.8	1.7	1.6	1.7	1.8	2.0	2.1	2.2	2.2	2.3	2.5	2.5	2.5	2.6	2.7	3.0	3.1	3.1	2.9	2.7	1.05
		2.3	1.8	1.6	1.7	1.6	1.5	1.5	1.5	1.6	1.6	1.8	2.0	2.0	2.1	2.1	2.2	2.3	2.4	2.6	2.6	2.7	2.8	2.9	1.1
			2.3	1.7	1.6	1.7	1.5	1.5	1.4	1.6	1.5	1.6	1.7	1.9	2.0	1.9	2.0	2.1	2.3	2.7	2.4	2.4	2.5	2.6	1.15
				2.0	1.6	1.6	1.5	1.4	1.3	1.5	1.6	1.5	1.6	1.9	1.9	1.9	1.8	1.8	2.0	2.2	2.2	2.3	2.3	2.4	1.2
					2.0	1.6	1.6	1.6	1.5	1.5	1.5	1.7	1.7	1.7	1.9	1.7	1.7	1.7	1.8	1.9	2.0	2.0	2.1	2.2	1.25
						2.2	1.8	1.7	1.7	1.8	1.7	1.6	1.6	1.7	1.7	1.6	1.6	1.6	1.7	1.8	1.7	1.9	1.9	2.0	1.3
							2.3	1.9	1.7	1.9	1.9	1.8	1.6	1.6	1.6	1.5	1.5	1.6	1.6	1.7	1.7	1.7	1.8	1.9	1.35
								2.7	2.1	1.8	1.7	1.8	1.7	1.8	1.7	1.5	1.4	1.5	1.6	1.7	1.6	1.6	1.7	1.8	1.4
									2.5	2.0	1.7	1.8	1.8	1.8	1.8	1.6	1.6	1.5	1.6	1.7	1.6	1.5	1.6	1.6	1.45
										2.4	1.9	1.8	1.8	1.9	1.9	1.7	1.7	1.6	1.7	1.8	1.6	1.6	1.5	1.6	1.5
											2.2	1.9	1.8	1.8	1.8	1.7	1.7	1.7	1.7	1.8	1.6	1.6	1.6	1.7	1.55
												2.3	1.9	1.9	1.8	1.6	1.7	1.8	1.7	1.7	1.7	1.6	1.6	1.6	1.6
													2.4	2.0	1.9	1.7	1.7	1.8	1.8	1.8	1.7	1.6	1.6	1.6	1.65
														2.4	2.1	2.0	1.9	1.9	1.9	2.0	1.8	1.8	1.7	1.7	1.7
															2.5	2.1	2.1	2.0	2.0	2.1	1.9	1.8	1.8	1.8	1.75
																2.4	2.1	2.1	2.0	2.1	2.0	1.8	1.7	1.7	1.8
																	2.5	2.2	2.2	2.2	2.0	1.8	1.7	1.7	1.85
																		2.6	2.4	2.4	2.2	2.0	1.9	1.8	1.9
																			2.9	2.7	2.4	2.2	2.1	2.0	1.95
																				3.3	2.7	2.4	2.3	2.2	2

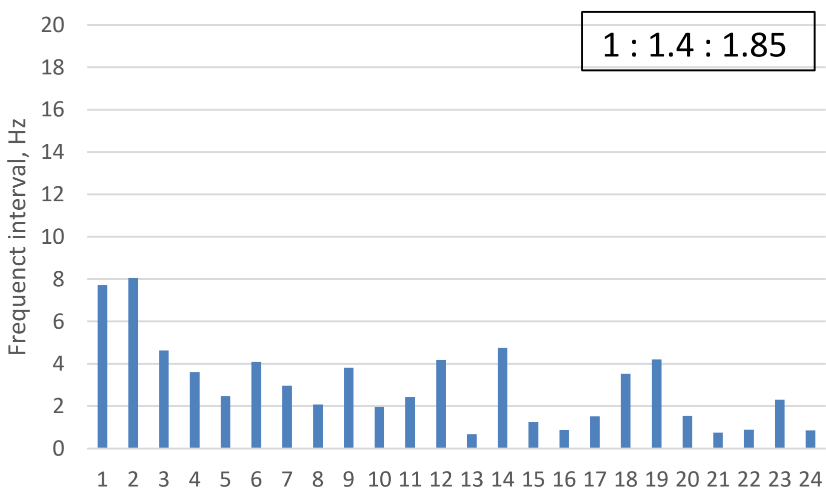
Worst cases

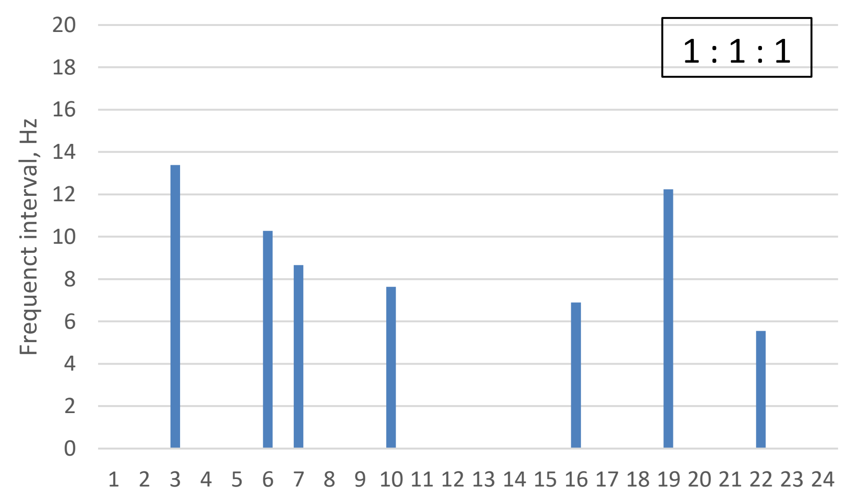
Best cases

Best – Worst (150 m³ rooms)







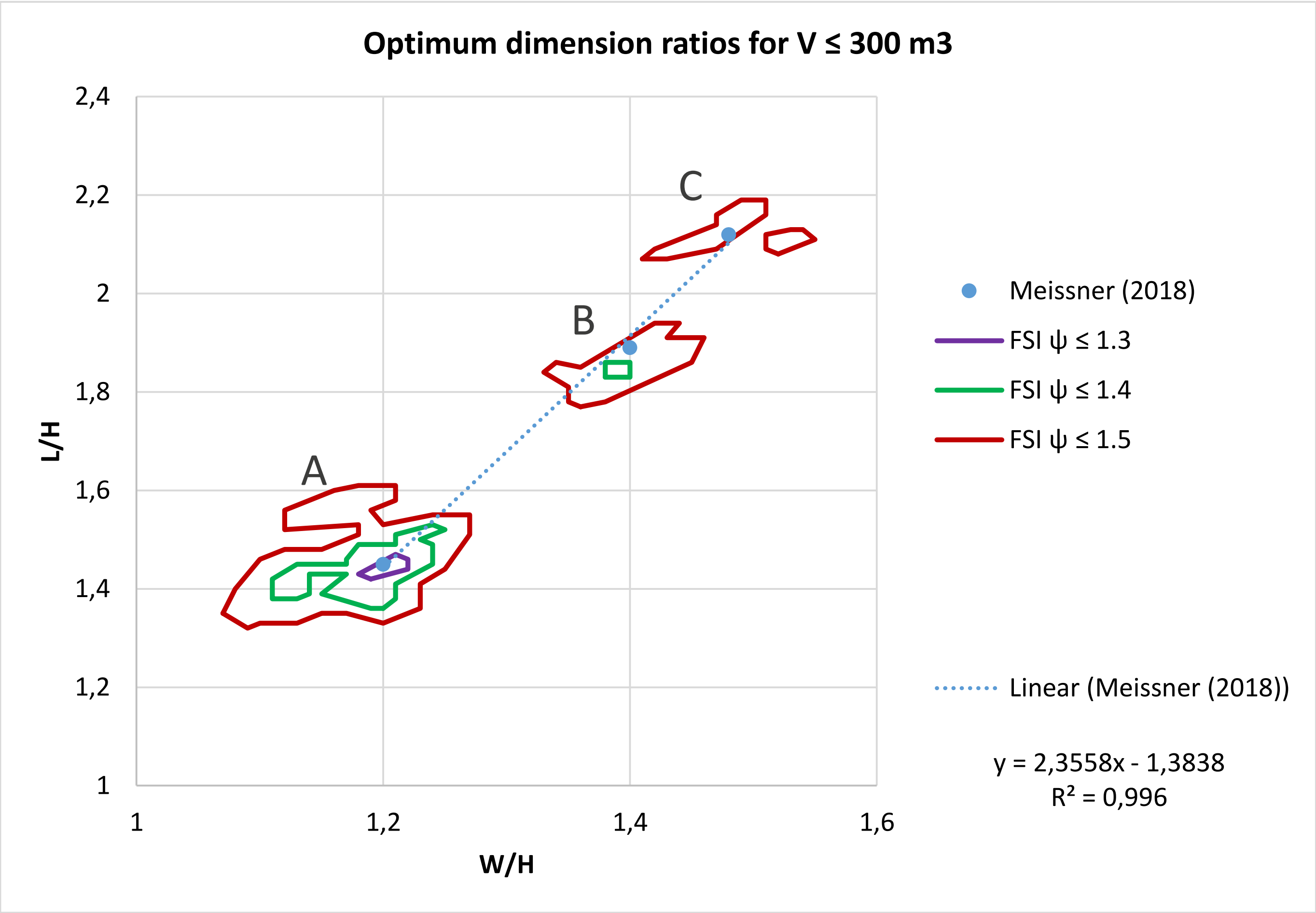


Comparison of three criteria

	Smoothness	Number of musical tones	Frequency spacing index
Room volume	Yes	Yes	No
Absorption of surfaces	Yes	No	No

- Agreement about three optima,
  - most precise with FSI, less accurate with musical tones

Optimum dimension ratios - Comparison of two methods

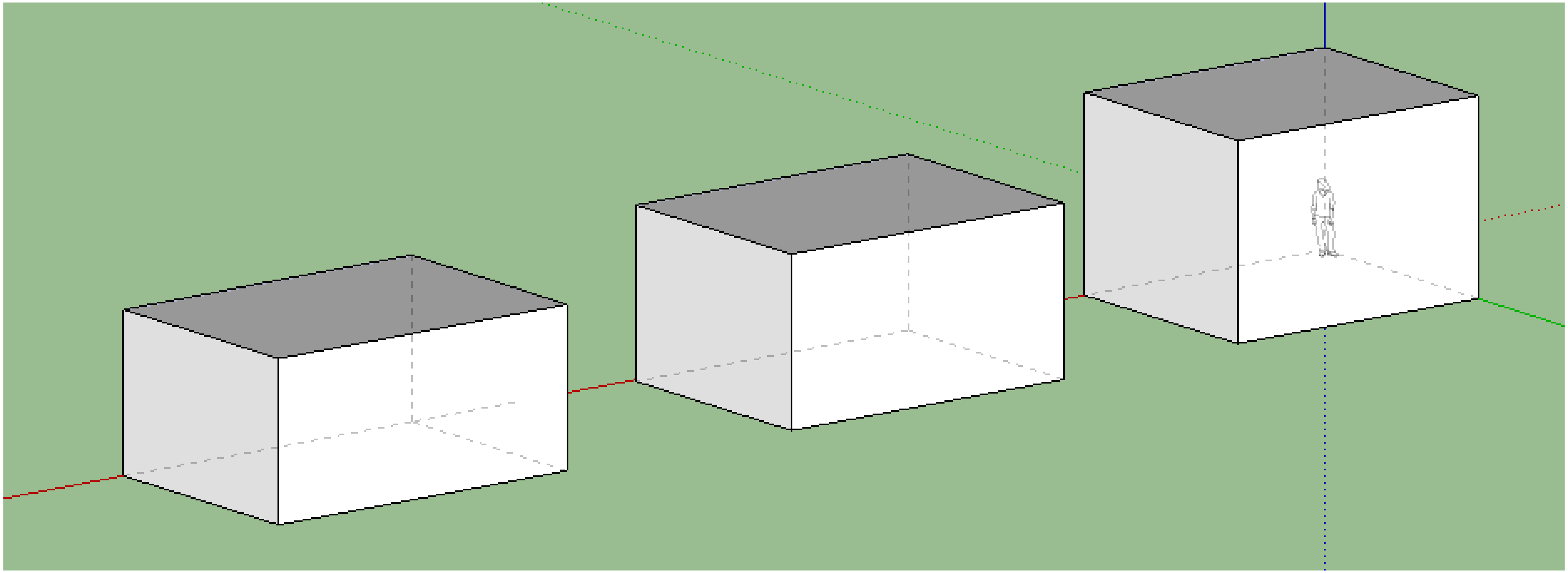


Optimum dimension ratios
- Isometric room sketches

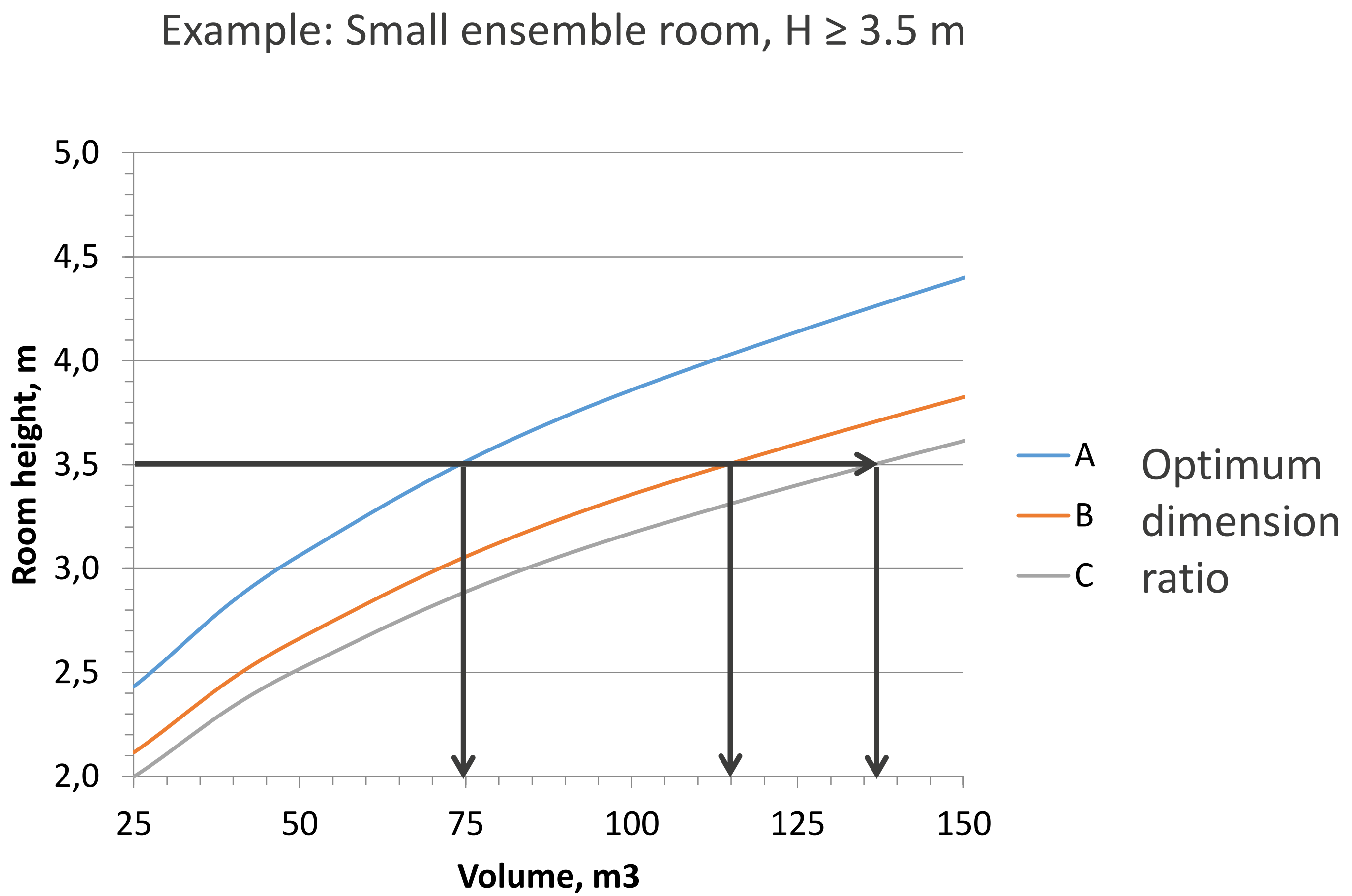
C 1 : 1.48 : 2.12

B 1 : 1.4 : 1.89

A 1 : 1.2 : 1.45



Volume vs. room height



Suggested method for choosing room dimensions

A range of nearly optimum dimension ratios can be applied instead of a few fixed dimension ratios. This is convenient for practical use when there are constrains on room height and volume.

The formula for the regression line is:

$$L/H = 2.36 \cdot W/H - 1.38$$

where

L is room length,

W is room width

H is room height.

The ratio *W/H* in formula should be within the range 1.2 to 1.6.

Conclusion

- The dimension ratio of a room has significant importance for the frequency distribution of room modes in small rooms.
- Several different "optimum" dimension ratios have been found in the literature.
  - However, nearly optimum dimension ratios can be obtained within a certain range around the optimum.
- Nearly optimum dimension ratios are found close to a linear regression line that establish a relation between L/H and W/H.
  - Using this relation for the room design ensures a nearly optimum dimension ratio with more freedom that using only optimum dimension ratios.
- NB: So far there is no research that show whether or not musicians prefer rooms with optimum dimension ratios.

References

- R.H. Bolt (1946). Note on Normal Frequency Statistics for Rectangular Rooms. JASA 18, 130-133.
- M: Meissner (2018). A Novel Method for Determining Optimum Dimension Ratios for Small Rectangular Rooms. Achives of Acoustics 43, 217-225.
- J.H. Rindel (2015). Modal Energy Analysis of Nearly Rectangular Rooms at Low Frequencies. Acta Acustica united with Acustica 101, 1211-1221.