Hand-in Assignment 3 (HA3):
Building Acoustics

Department of the Built Environment, Building Acoustics Group
7LS8M0 Architectural Acoustics

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Instructions

The guideline of the Hand-in Assignment 3 (HA3) includes the concepts as well as the tasks needed to be submitted. Your report is needed to be submitted on Canvas **before** the deadline. **Late submissions are not accepted, and graded with zero!** Your submitted report is needed to be in a **pdf** format and **named** such GroupNumber_Assignment.pdf (e.g., Group01_HA3.pdf) and your MATLAB scripts such GroupName_Assignment.m (e.g., Group01_HA3.m). In addition, both the MATLAB functions and scripts are needed to be separately submitted in a **zip** file. All the MATLAB scripts need to be commented very clearly, explaining what you are doing in every line of the code using comments. The figures must have the same format as the figure generated. All the generated figures need include title, labels in axes, and legends. In your report, the figures need to have a proper size, so that all the information to be well observable. At the appendix of your report, you need to include all your MATLAB codes. All the tasks are needed to be accomplished and included into the report. For collecting the full points per task, the answers should be fully motivated, correct and clear. Support your evidence with the proposed literature or other literature from your side. Finally, the distribution of points in HA3 is presented in Table 1.

Table 1: Distribution of Points in HA3.

	Tasks Sec. 2	Tasks Sec. 3	Structure/Lang.	References/Cites	Total
Points (pts)	4.00	3.00	0.50	0.50	8.00

1 Introduction

This assignment focuses on building acoustics and more specifically on the air-borne and structure-borne transmission of the sound in joint rooms. Measurements in joint rooms are analyzed so that the transmission loss between to joint room (in the horizontal plane) to be extracted. In addition, the impact sound level is going to be investigated with respect to joint rooms in the vertical plane. Similarly to the previous assignments, the frequency dependency is taken into consideration.

2 Airborne Sound Insulation

A number of airborne sound insulation measurements was conducted in the joint reverberation chambers in the Echo Building located in the TU/e. An overview of the conducted measurements is presented in Figure 1.

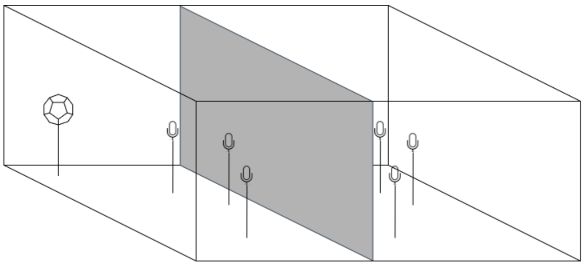


Figure 1: Airborne sound insulation setup.

The two reverberation chambers are separated by a surface $S = 10.3\ m^2$ (grey area). The left reverberation chamber, in which the sound source (i.e., dodecahedron) is located, corresponds to the source room and its volume is $V_s = 90\ m^3$, whereas the right reverberation chamber corresponds to the receiver room and its volume is $V_r = 83\ m^3$. In the receiver room, absorption panels have been added so that the reverberation time to be reduced in significant levels. For the airborne insulation measurements, a noise signal was used and the sound pressure level (SPL) in 1/3-octave frequency bands was measured in three microphone positions in both the source and the receiver room. At the positions where SPL was measured in the receiver room, both the reverberation time (T_{30}) and the background noise levels (L_b) were captured with respect to 1/3-octave frequency bands. These measurements are summarized in Table 1 and Table 3, respectively. By combining all the measured quantities, sound reduction index (or sound transmission loss) per 1/3-octave frequency band is calculated, using eq. (1). In general, sound reduction index (R) corresponds to the loss which is occurred when the sound is transmitted from one room to another room through a partition. High values of R indicate that less acoustic energy is transmitted via the surface from the source to the receiver room.

Mathematically, the sound reduction index (R) is defined such,

$$R = L_s - L_r + 10\log_{10}\frac{S}{A_r} \quad [\text{dB}] \tag{1}$$

where L_s is the sound pressure level in the source room (dB), L_r is the sound pressure level in the receiver room (dB), S is the area of the partition (m^2), and A_r is the absorption area of the receiver room (m^2).

The absorption area (A_r) is calculated via the Sabine's formula for reverberation time, which is defined such,

$$T_{r,60} = 0.161 \cdot \frac{V_r}{A_r} \quad [s] \longrightarrow A_r = \frac{0.161 \cdot V_r}{T_{r,60}} \quad [m^2] \tag{2}$$

where V_r is volume of the receiver room (m^3), and $T_{r,60}$ is the reverberation time in the receiver room (s).

Table 2: Measured sound pressure levels in the source ($L_{s,m}$) and the receiver ($L_{r,m}$) room per 1/3-octave frequency band and position m.

	Source Room			Receiver Room		
Frequency Band (Hz)	$L_{s,1}$ (dB)	$L_{s,2}$ (dB)	$L_{s,3}$ (dB)	$L_{r,1}$ (dB)	$L_{r,2}$ (dB)	$L_{r,3}$ (dB)
100	72.6	74.7	74.0	49.0	52.9	53.9
125	75.1	76.3	76.2	56.9	57.8	56.2
160	77.8	78.7	78.8	57.8	59.7	58.2
200	75.5	76.5	75.4	55.2	53.7	54.6
250	73.8	73.1	73.1	53.2	54.7	54.1
315	73.0	72.6	73.3	51.3	51.3	50.1
400	72.1	71.1	72.0	48.6	48.4	46.9
500	69.0	69.4	69.9	44.9	44.5	43.3
630	67.9	67.6	67.9	41.7	41.6	41.0
800	66.5	66.9	66.4	40.3	41.0	39.7
1000	64.9	64.6	64.8	40.1	40.1	38.2
1250	65.1	65.3	65.4	45.8	46.0	45.5
1600	67.2	67.1	67.4	43.2	43.8	42.1
2000	64.9	65.4	65.1	33.6	33.7	32.2
2500	64.0	64.3	64.4	30.1	30.8	29.8
3150	62.5	62.9	62.8	29.8	30.2	29.0

Table 3: Measured reverberation time ($T_{30,m}$) and background noise ($L_{b,m}$) per 1/3-octave frequency band and position m in the receiver room.

	Reverberation Time			Background Noise		
Frequency Band (Hz)	$T_{30,1}$ (s)	$T_{30,2}$ (s)	$T_{30,3}$ (s)	$L_{b,1}$ (dB)	$L_{b,2}$ (dB)	$L_{b,3}$ (dB)
100	0.59	0.56	0.69	09.4	09.6	09.5
125	1.24	0.75	1.15	09.0	08.5	08.8
160	0.61	1.08	0.96	08.4	08.4	08.7
200	0.67	0.53	0.58	08.1	07.1	07.5
250	0.55	0.48	0.54	08.0	06.8	07.3
315	0.55	0.59	0.58	08.1	06.6	07.2
400	0.57	0.58	0.66	08.4	06.5	07.2
500	0.63	0.54	0.62	09.1	07.3	07.4
630	0.63	0.54	0.65	11.1	08.1	08.1
800	0.66	0.67	0.60	10.1	09.1	08.6
1000	0.67	0.57	0.68	10.4	08.9	09.2
1250	0.67	0.59	0.65	09.1	08.5	08.6
1600	0.71	0.66	0.70	09.0	08.5	08.6
2000	0.67	0.70	0.69	09.3	09.2	09.2
2500	0.57	0.69	0.68	09.9	09.9	10.0
3150	0.65	0.65	0.66	10.9	10.8	10.8

Tasks [2.00 pts]

2.0.A Import the data assigned to Table 2 and Table 3 in your MATLAB script. In terms of the data forms, construct four matrix variables and assign the data per 1/3-octave frequency band. Also, assign the central frequencies of the 1/3-octave frequency bands in a separate vector variable.

2.0.B Compute the average sound pressure level per 1/3-octave frequency band for the source and the receiver room, using eq. (3),

$$L_{dB} = 10 \cdot \log_{10}\left(\frac{1}{M}\sum_{m=1}^{M} 10^{L_m/10}\right) \quad \text{[dB]} \tag{3}$$

where L_m corresponds to the pressure level per position m.

2.0.C Compute the average reverberation time per 1/3-frequency band for the receiver room.

2.0.D Compute the average absorption area per 1/3-frequency band for the receiver room.

2.0.F Compute the average background noise level[1] per 1/3-octave frequency band, using eq. (3).

2.0.G Plot the average background noise level (L_b) per 1/3-octave frequency band. In the same figure, plot the average level in the receiver room (L_r) as well as the difference between average level in the receiver room and background noise level ($L_r - L_b$) per 1/3-octave frequency band. Discuss the quality of the measurements.

2.0.H Compute & plot the average sound reduction index (R) per 1/3-octave frequency band, using eq. (1).

2.1 Evaluation of the Measured Sound Reduction Index via a Single Quantity

According to the ISO 717-1:2013 [1], a reference curve should be used for evaluating the measured sound reduction index. The values of the reference curve, corresponding to airborne sound insulation, are given in Table 4.

Table 4: Reference values for airborne sound per 1/3-octave frequency band [1].

f_c (Hz)	100	125	160	200	250	315	400	500	630	800	1k	1.25k	1.6k	2k	2.5k	3.15k
R_{ref} (dB)	33	36	39	42	45	48	51	52	53	54	55	56	56	56	56	56

For allowing the comparison between the average sound reduction index and the reference curve, a fitting procedure is needed to be conducted. This procedure focuses on the increment of the reference curve by +1dB or −1dB, so that the sum of *unfavorable deviations* to be as large as possible, but no more than 32dB. The term of unfavorable deviations correspond *only* to the difference between the values of the measurements (i.e., which are less than the reference values) and the values of the reference curve at the respective 1/3-octave frequency bands, expressed such $L_{fit,ref} - L_{meas}$, $\forall f_c : L_{fit,ref} > L_{meas}$. These values at the respective frequency bands are used for calculating the sum of unfavorable deviations, using the expression,

$$L_{diff} = \log_{10}\left(10^{\sum (L_{fit,ref} - L_{meas})}\right), \quad \forall f_c : L_{fit,ref} > L_{meas} \tag{4}$$

After this procedure, the value of the shifted reference curve at 500Hz is determined, corresponding to the weighted sound reduction index[2] (R'_w), which is a single-number quantity. This single quantity has shown significant associations to annoyance [4]. An example of this procedure is presented in the Figure 2. The data used for the representation of the example is included into the reference [1].

[1] Note: The measurement of the background noise is used for the implication of correction term(s) in average sound pressure level of the receiver room if the background noise level is higher by 6dB or preferably by 10dB. For further information, see reference [1].

[2] Note that only 12 out of 24 European countries (i.e., last update 2008) have adopted the descriptor R'_w. The Netherlands is not part of mentioned 12 countries. For further information see reference [3].

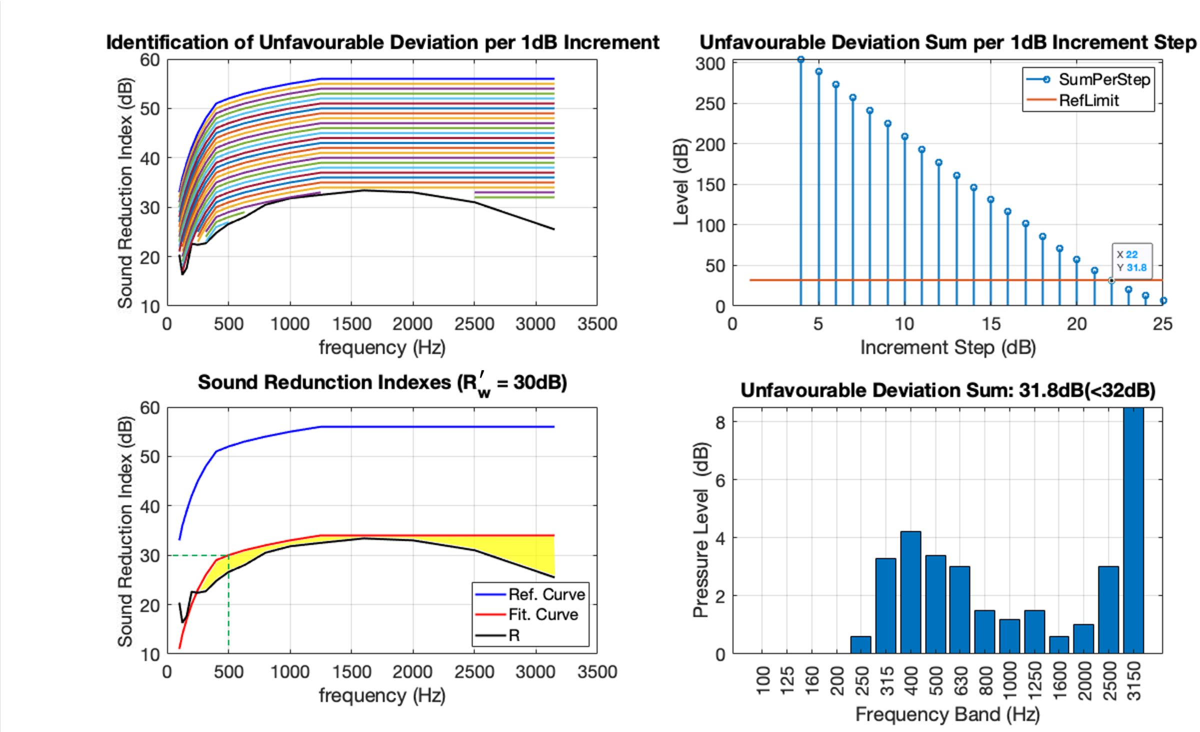


Figure 2: Graphical representation of the methodology for estimating the correct fitted reference curve to the measured curve, and R'_w.

Focusing on the example in Figure 2, for estimating the correct reference fitted curve (red line: bottom-left plot), a step of -1dB was used, since the measured curve (black line: bottom-left and -right plot) is lower than reference curve (blue line: bottom-left and -right plot). Per increment step (multi-colour lines: top-left plot), the values of reference curve, which fulfill the condition for the unfavorable deviation, have been plotted (top-left plot). In total 25 steps have been used, corresponding to -25dB. The sum of the unfavourable deviations per 1dB increment step has been also calculated and plotted in the top-right side of the Figure 2, including the reference level of 32dB and pinpointing the first value which is closer to reference level (i.e., 31.8dB). Note that the none presence of values in first 3 steps corresponds to infinity. Also, the pinpointed value indicates that the correct fitted reference curve is the $R_{ref,fit} = R_{ref} - 22dB$, where 22 is the increment step. The unfavorable deviations of the correct reference fitted curve are also plotted in bottom-right plot in Figure 2. These values correspond to the yellow-shaded area in the bottom-left plot in Figure 2. Here, the none presence of values at 100, 125, 160, and 200Hz indicates that the unfavorable deviations do not fulfill the condition $R_{ref} < R$. Finally, having been identified the correct reference fitted curve (red line: bottom-left plot), the value of the weighted sound reduction index is extracted (green dashed-line: bottom left plot), which is $R'_w = 30dB$.

Tasks [2.00 pts]

2.1.A Import the reference values of the airborne sound insulation (i.e., Table 4) into your script.

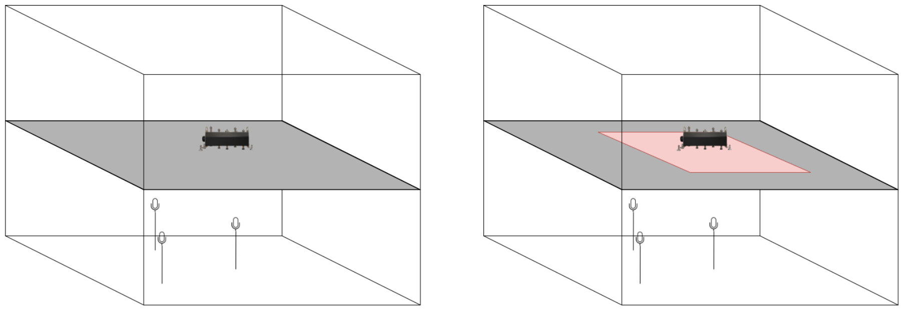
2.1.B Open the `FitRefCurve.m` function and fill-in only the parts pointed by three dots (...). This function returns the correct reference fitted curve, its unfavourable deviations, and the weighted sound reduction index R'_w with respect to the methodology described in this subsection.

2.1.C Include to your report the figure which is automatically produced by `FitRefCurve.m` and discuss it.

2.1.D Assuming that data from ref. [4] holds to measured data, where $R'_w \in [46, 65]$ corresponds to annoyance to speech (30%) & music (39%), how would you describe the airborne insulation between the chambers?

3 Impact Sound Insulation

In the previous section, the main focus was on the airborne sound insulation between two rooms separated by a surface. In this section, the attention is given to the impact sound insulation via two joint rooms in the vertical plane (see Figure 3). Again here, the room in which the noise source is located correspond to source room, whereas the room in which three microphones are located correspond the receiver room. The volume of the receiver room is $V_r = 83m^3$.



(a) Setup 1: Without the carpet.

(b) Setup 2: With the carpet.

Figure 3: Impact sound insulation measurement setups.

Impact sound insulation measurements are conducted using a tapping machine (i.e., see Figure 3). This type of sound (noise) source is commonly used for the assessment or class of the impact sound insulation of a floor. The tapping machine includes a number of hammers in its lower part. When the source is activated, the hammers are released and fall on the floor 10 times per second, generating a train of pulses. In the receiver room, the sound pressure level was measured per 1/3-octave frequency bands in three positions.

For this part of the assignment, two main measurement setups have been considered (i.e., see Figure 3); the implementation of the tapping machine in,

- a wooden floor directly (i.e., see Figure 3a), and
- a wooden floor covered by a carpet (i.e., see Figure 3b).

In both setups, the sound pressure levels (SPLs) measured in 1/3-octave frequency bands in the receiver room, and measurements are summarized in Table 5.

The impact sound level in the receiver room (L_n) is computed, using the expression,

$$L_n = L_r + 10 \log_{10} \frac{A_r}{A_0} \quad [dB] \tag{5}$$

where L_r is the average sound pressure level in the receiver room (dB), A_r is the absorption area in the receiver room (m^2), and A_0 is the reference absorption which corresponds to 10 m^2.

Note that since the same room has been used as a receiver room for both airborne and impact sound insulation measurements as well as the measured quantities captured at the same locations, the values of the reverberation time (T_{30}) and the background noise level (L_b) presented in Table 3 can be also used for the tasks in this section.

Table 5: Measured sound pressure level in the receiver room ($L_{r,m}$) without and with the addition of the carpet per 1/3-octave frequency band and position m.

	Setup 1: Without the Carpet			Setup 2: With the Carpet		
Frequency Band (Hz)	$L_{r,1}$ (dB)	$L_{r,2}$ (dB)	$L_{r,3}$ (dB)	$L_{r,1}$ (dB)	$L_{r,2}$ (dB)	$L_{r,3}$ (dB)
100	53.5	55.9	58.1	48.2	51.0	52.5
125	56.3	54.3	57.0	47.4	47.4	49.0
160	56.1	58.7	60.8	43.2	47.7	49.2
200	60.2	62.6	65.4	42.2	45.8	47.2
250	61.4	59.8	64.3	40.8	39.6	44.4
315	64.9	65.0	64.2	40.7	40.6	41.3
400	62.0	64.5	66.8	42.4	42.3	44.0
500	61.1	60.3	62.7	39.3	40.6	42.3
630	61.9	61.5	63.5	37.8	39.6	39.8
800	60.3	62.5	63.3	40.1	40.4	40.9
1000	56.2	57.1	61.2	37.3	37.3	37.6
1250	61.1	59.1	61.3	36.8	36.6	37.8
1600	52.7	50.7	53.2	35.0	35.2	37.3
2000	44.1	42.9	45.2	36.0	36.4	37.1
2500	40.0	39.3	41.9	36.0	36.9	37.1
3150	37.9	37.9	37.6	35.8	36.5	36.4

Tasks [3.00 pts]

3.0.A Compute the average sound pressure level per 1/3-frequency band for the receiver room for both cases, using eq. (3).

3.0.B Similar to **Task 2.0.G**, plot the average background noise level (L_b) per 1/3-octave frequency band. In the same figure, plot the average level in the receiver room (L_r) as well as the difference between average level in the receiver room and background noise level ($L_r - L_b$). Discuss the quality of these measurements, as well.

3.0.C Compute and plot the average impact sound level per 1/3-frequency band for both cases, using eq. (5).

3.0.D Again here, for allowing the evaluation of the measured data, the methodology of fitting the reference curve for the impact sound level in the measured curves is going to be implied. The values of the reference curve for impact sound level are presented in Table 6. Import the reference values of the airborne sound insulation into your script.

Table 6: Reference values for impact sound level per 1/3-octave frequency bands, as they are given in the ISO 717-2:2013 [2].

f_c (Hz)	100	125	160	200	250	315	400	500	630	800	1k	1.25k	1.6k	2k	2.5k	3.15k
$L_{n,ref}$ (dB)	62	62	62	62	62	62	61	60	59	58	57	54	51	48	45	42

3.0.E Using the `FitRefCurve.m`, constructed in **Task 2.2.B**, fit the reference impact sound level curve to both measured cases (i.e., L_n without and with carpet). Compare and discuss the figures produced automatically.

3.0.F Assuming that data from ref. [4] holds to measured data, where $L'_w \in [41, 60]$ corresponds to annoyance to footfall noise (85%), how would you describe the impact sound insulation between the chambers before and after the usage of carpet?

References

[1] ISO 717-1:2013. *Acoustics - Rating of sound insulation in buildings and of building elements - Part 1: Airborne sound insulation.*

[2] ISO 717-2:2013. *Acoustics - Rating of sound insulation in buildings and of building elements - Part 2: Impact sound insulation.*

[3] Birgit Rasmussen. Sound insulation between dwellings - requirements in building regulations in europe. *Applied Acoustics*, 71:373–385, 2010.

[4] Jens Holger Rindel, Anders Lovstad, and Ronny Klaeboe. Dose-response curves for satisfactory sound insulation between dwellings. In *12th ICBEN Congress on Noise as a Public Health Problem*, Zurich, Switzerland, 2017.