Zvok, hrup, zvočne izolacije in vibracije

Doc. dr. Roman Kunič
Asist. Luka Pajek
Doc.dr. Mateja Dovjak

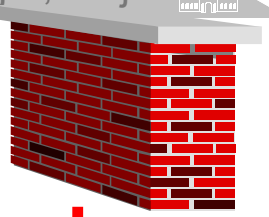
Univerza v Ljubljani, Fakulteta za gradbeništvo in geodezijo,
Katedra za stavbe in konstrukcijske elemente

roman.kunic@fgg.uni-lj.si

Zvočna izolacija v stavbah

–LOČIMO:

- Zvočna izolacija proti zvoku v zraku ✓
- Zvočna izolacija proti udarnemu zvoku ✓
- Zvočna zaščita proti prenosu obratovalne opreme in vibracij inštalacij ✓
- Zvočna zaščita proti hrupu iz okolja – komunalnemu hrupu ✓
- Akustika notranjih prostorov (odmevni hrup) ✓



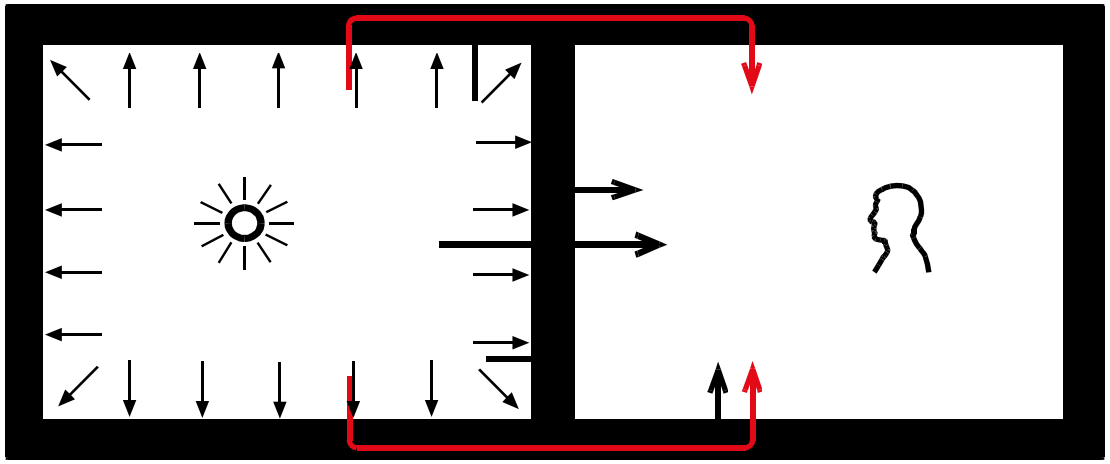
Zvočna izolacija pred zvoku v zraku:

- ODDAJNIK: vibracije zvoka v zraku (govor, zvočnik, glasbeni instrumenti…)
- PRENOSNIK: zrak, masivna konstrukcija, predelna stena, vrata, okno in zopet zrak
- SPREJEMNIK: zvok v zraku v drugem prostoru (uho, mikrofon…)

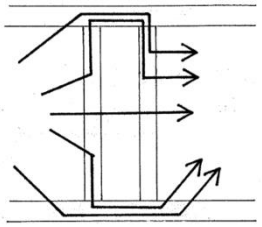
OSNOVNO PRAVILO: čim večja masa stene, stropa ali vmesne ovire na enoto površine

- Zvočno izolativni (porozni) materiali primarno zmanjšujejo samo odmev v (oddajnih ali sprejemnih) prostorih, ne vplivajo pa direktno na prehoda zvoka

Načini prehoda zvočne energije preko vmesne pregrade



Energija zvoka je približno konstantna po prostoru in na vseh šestih površinah prehaja v gradbeni material.

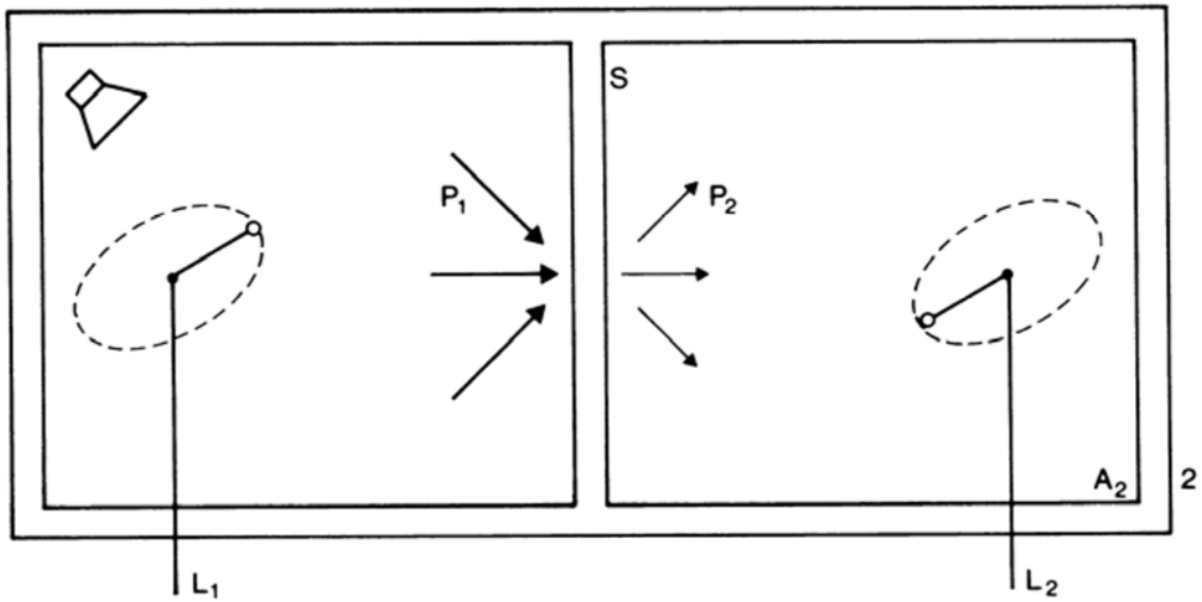


Prehod zvoka skozi dvojni zid

Zvočna energija prehaja med prostori:

- skozi steno, ki ju ločuje
- skozi stranska zidove (tako imenovani stranski prenos)
- po kombiniranih poteh
- skozi odprtine (fuge) in inštalacije

Meritve dokazovanja zvočne izolirnosti proti zvoku v zraku

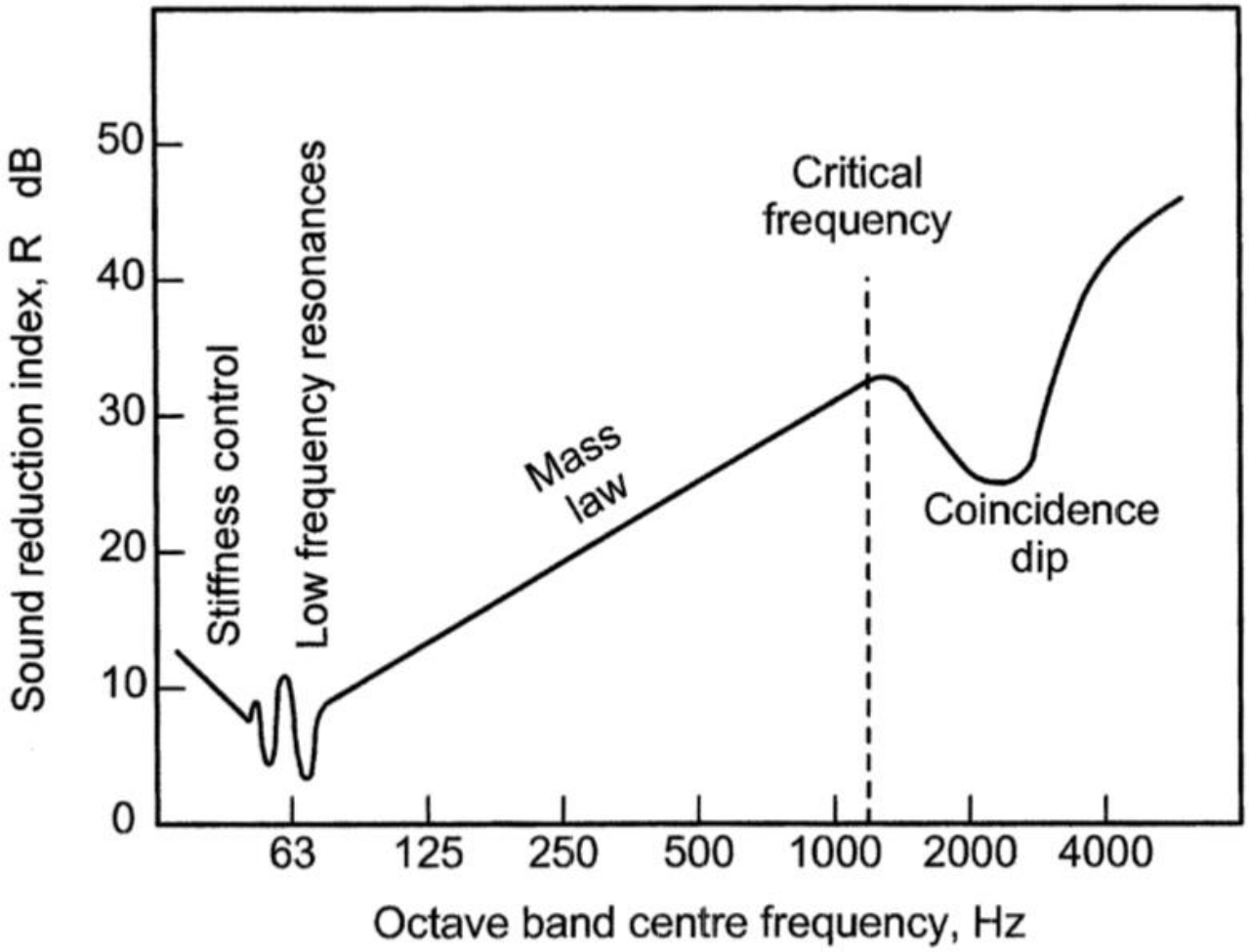


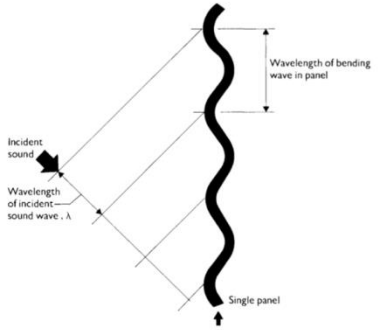
Zvočna izolirnost (R'_w) - Sound reduction index:

$$R'_w = L_1 - L_2 + 10 \log (S/A) = L_1 - L_2 + 10 \log (RT/RT_0)$$

L_1 in L_2 predstavljata nivo zvočnega tlaka v oddajnem in sprejemnem prostoru, S je površina skupne pregradne konstrukcije (m^2), A ekvivalentna absorpcijska površina v sprejemnem prostoru (m^2), RT odmevni čas v sprejemnem prostoru (s), RT_0 normalizirana vrednost odmevnega časa (s)

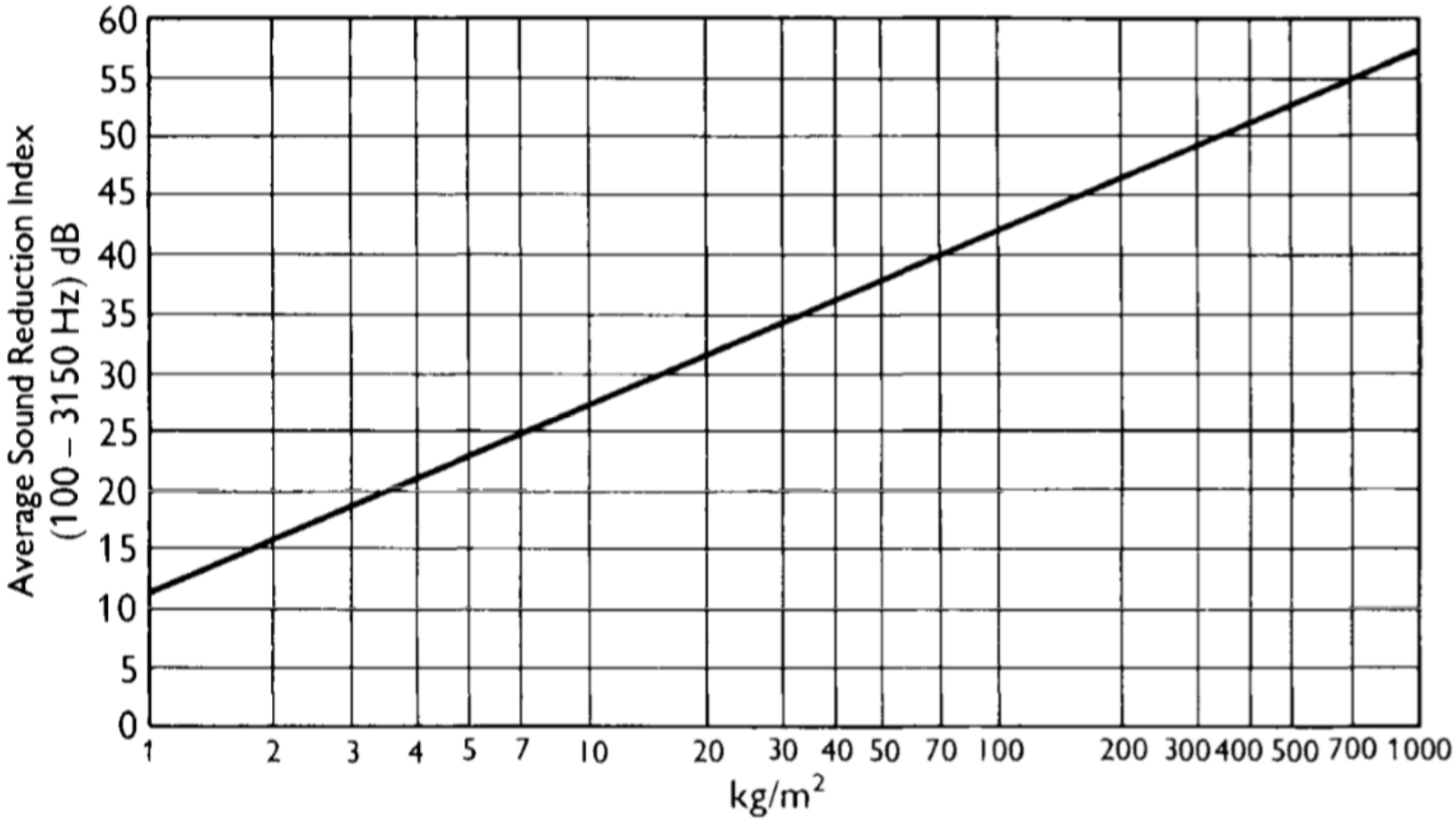
Zakon mase, resonančna in koincidenčna frekvenca





Theoretical variation of sound reduction index with frequency for a single panel.

Zakon mase: čim večja masa pregrade na enoto površine, tem večja je zvočna izolirnost (dvojna masa predstavlja cca. 6 dB boljšo izolirnost)

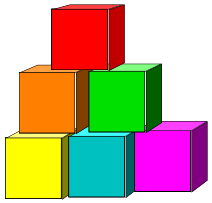


$$R \propto 20 \log (f\, m_s)$$

f - frekvenca (Hz), m_s - površinska masa pregrade (kg/m^3)

Zvočna izolacija proti udarnemu zvoku:

- ODDAJNIK: vibracije, hoja, udarci, premikanje stolov in pohištva, razne montaže in gradbeno-obrtniška dela
- PRENOSNIK: masivna konstrukcija in nato zrak
- SPREJEMNIK: zvok v zraku v drugem prostoru (uho...)



OSNOVNO PRAVILO: preprečiti moramo dostop udarnega zvoka v nosilno masivno konstrukcijo (stene ali medetažne konstrukcije) – vsi drugi pristopi so manj uspešni

Zvočna izolacija pred udarnim zvokom

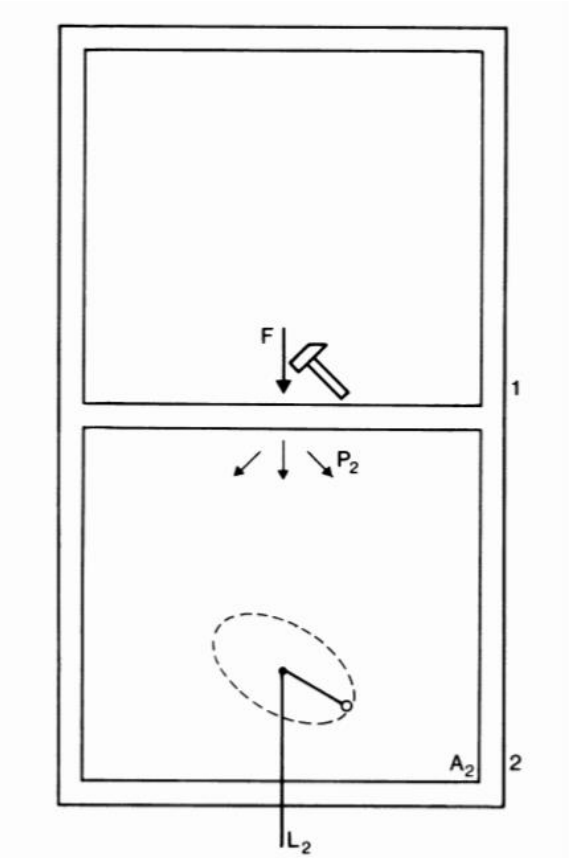


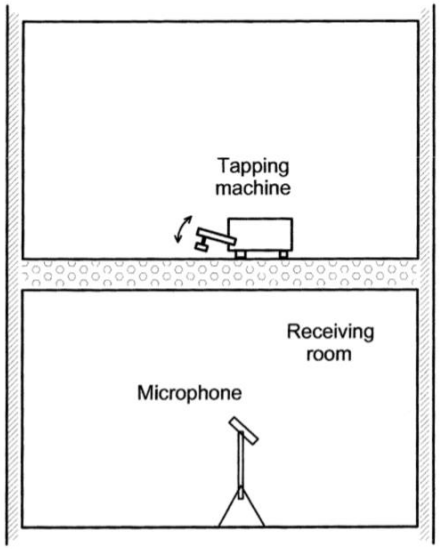
Fig. 5.6.1. Principle of measuring the impact sound pressure level from a floor to a receiving room (2)

Za vzbujanje udarnega zvoka uporabljamo standardni izvor udarnega zvoka ("tolkalo")

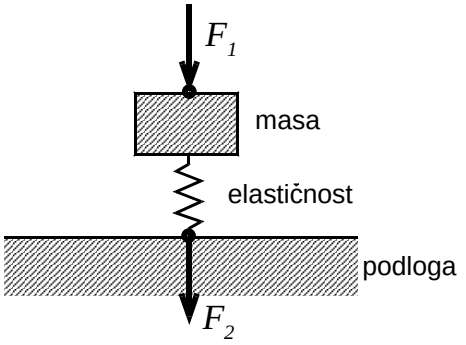
Normaliziran nivo zračnega tlaka udarnega zvoka (L'_N) :

$$L'_N = L'_1 + 10 \log (A/A_0) = L'_1 + 10 \log (RT/RT_0)$$

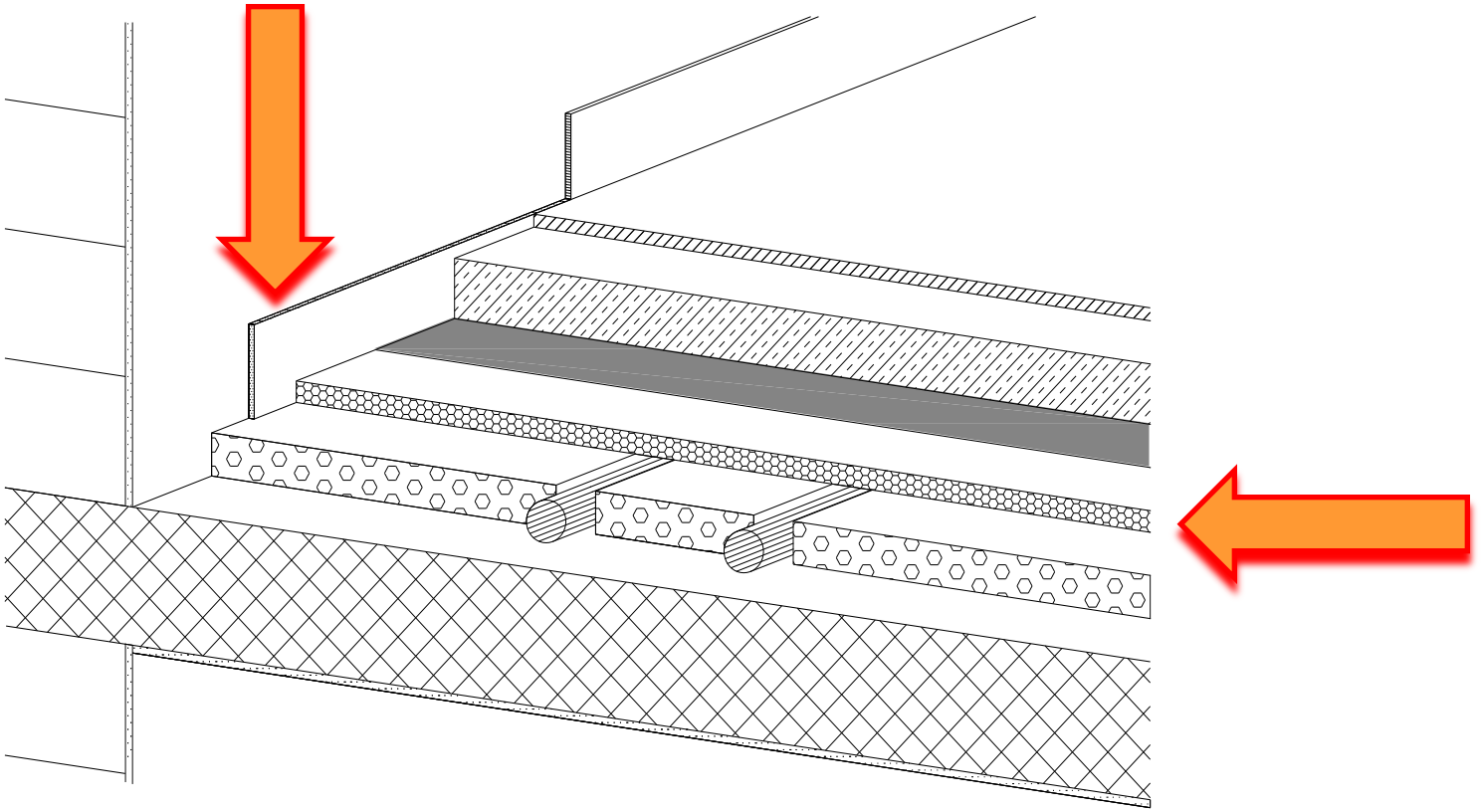
L'_1 predstavlja nivo zvočnega tlaka sprejemnem prostoru, A je ekvivalentna absorpcijska površina v sprejemnem prostoru (m^2), A_0 normalizirana ekvivalentna absorpcijska površina v sprejemnem prostoru (m^2), RT odmevni čas v sprejemnem prostoru (s), RT_0 normalizirana vrednost odmevnega časa (s)



Pair of rooms with tapping machine.

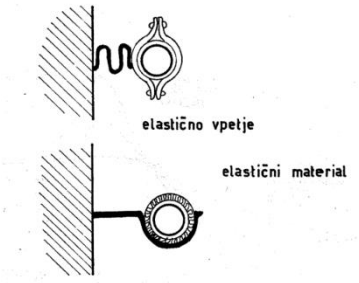


Plavajoči pod / plavajoči estrih



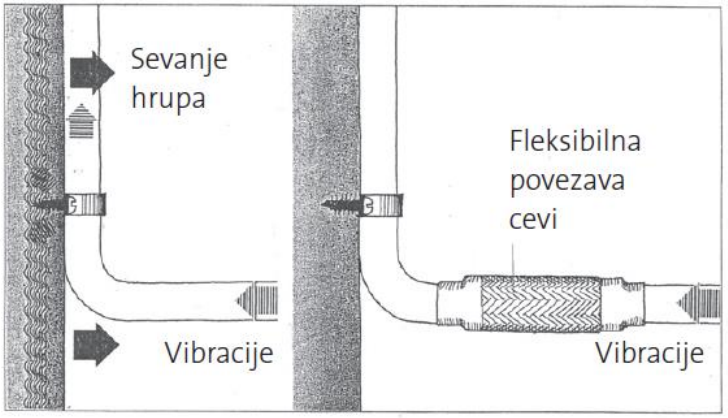
Zvočna zaščita proti prenosu obratovalne opreme in vibracij inštalacij :

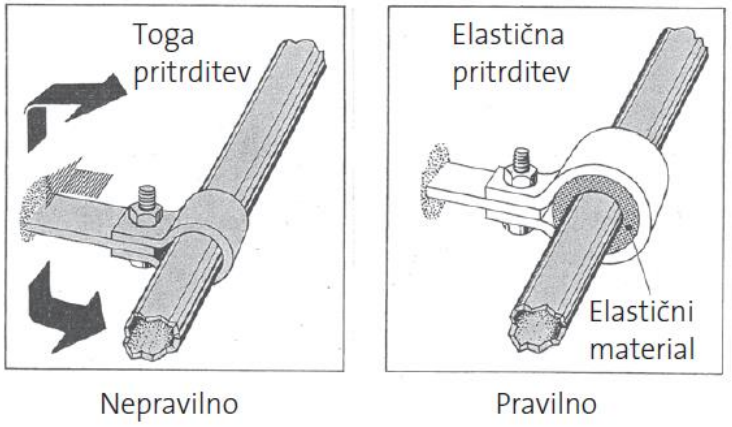
- ODDAJNIK: vibracije in vsiljeno nihanje inštalacij in druge obratovalne opreme, prenosa zvoka iz zraka ali udarnega zvoka na razvode inštalacij,
- PRENOSNIK: vodi inštalacij ali oslabitve ob prehodih inštalacij, masivne in nosilne konstrukcije
- SPREJEMNIK: zvok v zraku v drugem prostoru (uho...)



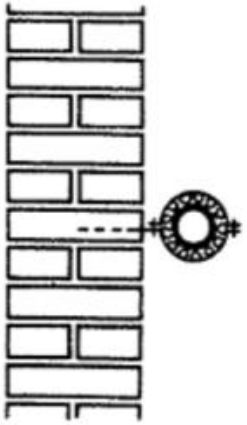
OSNOVNO PRAVILO:
preprečiti moramo dostop zvoka v inštalacijske vode,
Prenos vsiljenega nihanja ali vibracij
toge kontakte z masivnimi konstrukcijami,
zatesnitev prehodov inštalacij z elastičnimi in zvočno izolirnimi materiali

Preprečevanje neposrednega vzbujanja gradbenih konstrukcij z virom vibracij obratovalne opreme (tehnična smernica ‚Zaščita pred hrupom v stavbah')

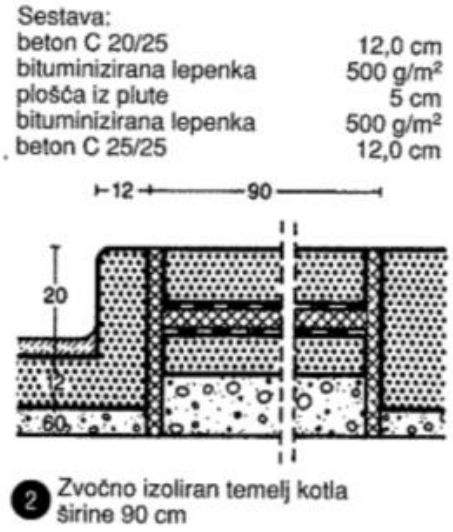




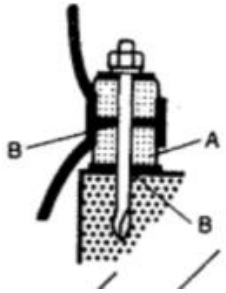
Risba 7: Načini pritrditve cevi za vodo na gradbeno konstrukcijo z namenom zmanjšanja hrupa zaradi neposrednega vzbujanja gradbene konstrukcije

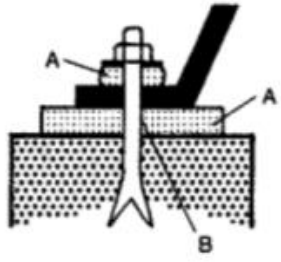


1 Zvočno izolirana objemka



2 Zvočno izoliran temelj kotla širine 90 cm





Hrup v okolju – komunalni hrup

- izvor hrupa je običajno: promet (cestni, železniški, letalski, pomorski….), industrija, otroška igrišča, prireditve…
- protihrupne ovire (bariere)

Ločimo:

- Aktivna protihrupna zaščita (zniževanje hrupa na strani povzročitelja) – zelo uspešna in cenejša
- Pasivna protihrupna zaščita (zniževanje hrupa na strani sprejemnika) – manj uspešna in dražja

Hrup v okolju – komunalni hrup

d

Protihrupne ograje / Zvočne bariere

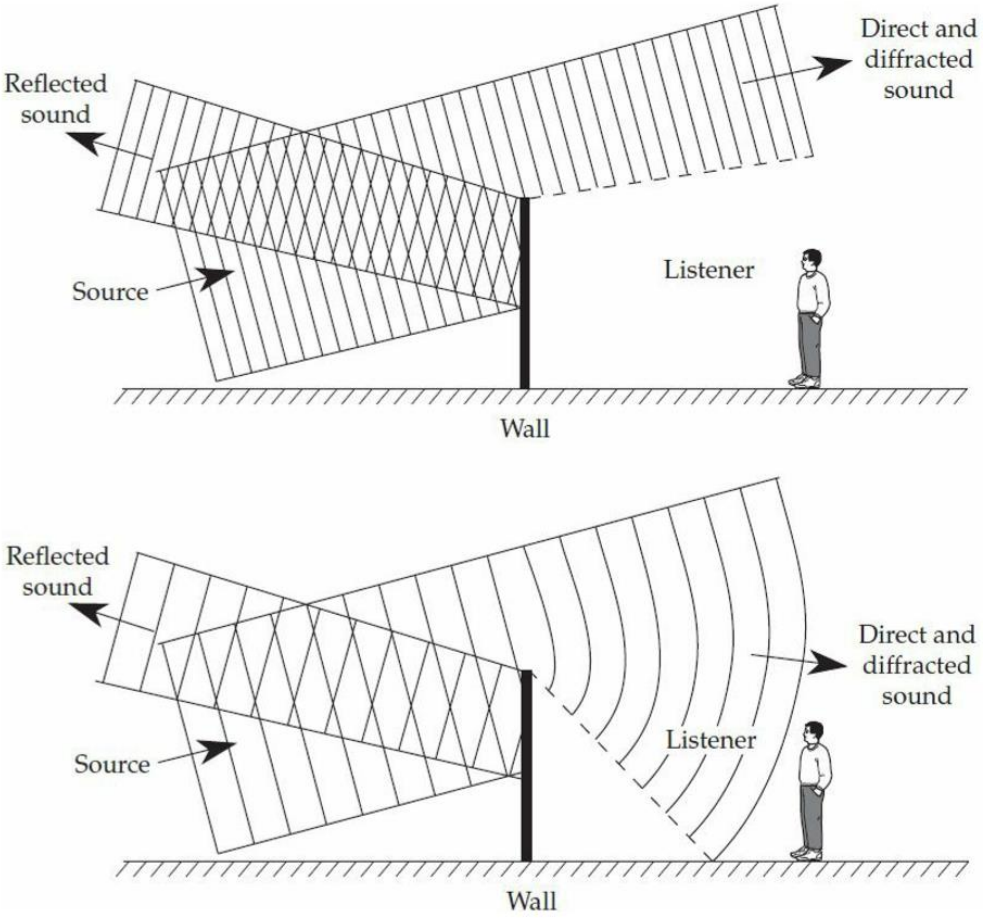
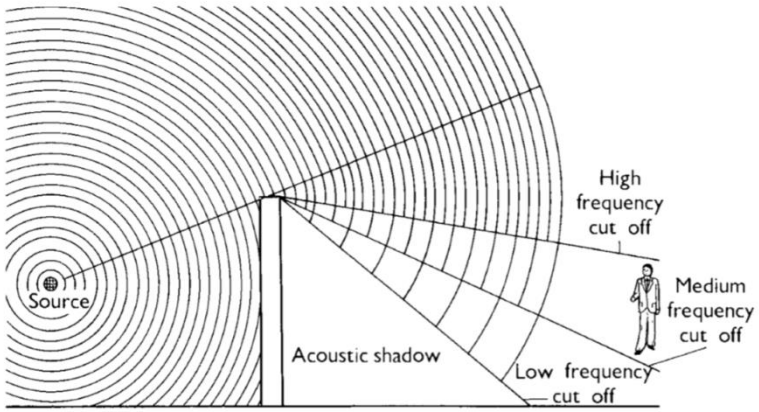


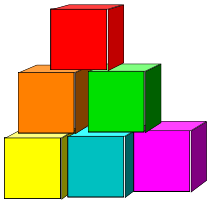
FIGURE 7-3 The sound striking a solid traffic barrier will be partly diffracted and partly reflected. (A) High-frequency traffic sounds are successfully attenuated on the other side of the barrier because of limited diffraction. (B) Low-frequency traffic sounds are less attenuated because of more prominent diffraction. Sound passing the top edge of the barrier acts as though the wavefronts are lines of sources, radiating sound energy into the shadow zone.



Primer izvedbe protihrupne bariere za atrij in pripadajoče fasade v atriju – uporaba steklene fasade

Tudi ozelenjene fasade in vegetacija pomaga k dušenju komunalnega hrupa

Akustika notranjih prostorov:



- cilj je regulacija odmevnega časa v notranjih prostorih
- akustika prostorov namenjenih govoru (pomembna je razumljivost)
- akustika prostorov namenjenih glasbi (pomembni so estetski kriteriji)
- odmevni čas zmanjšamo z namestitvijo absorpcijskih površin na stene, strop in tla notranjih prostorov

Odmevni čas TR_{60} (s)

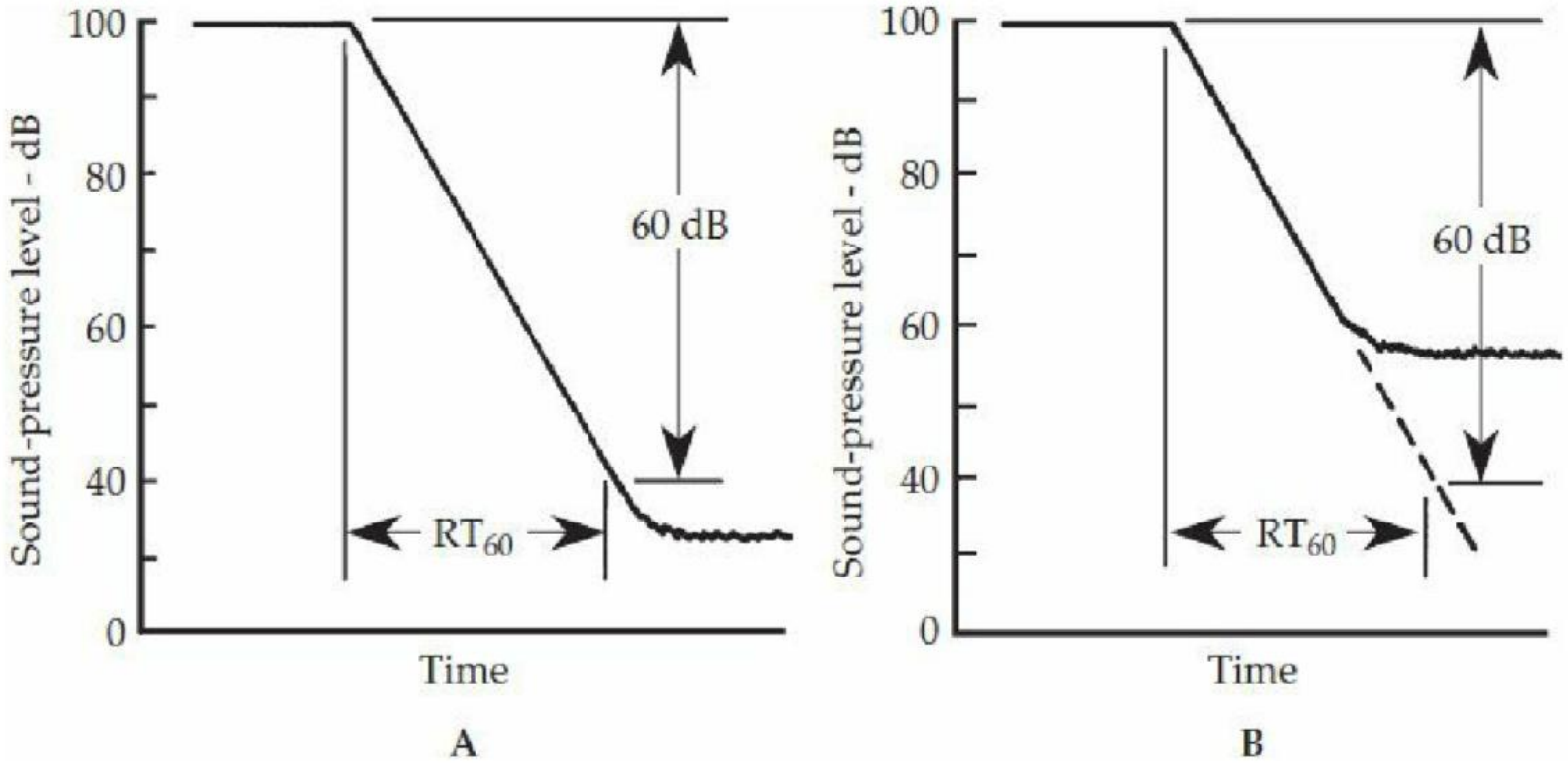


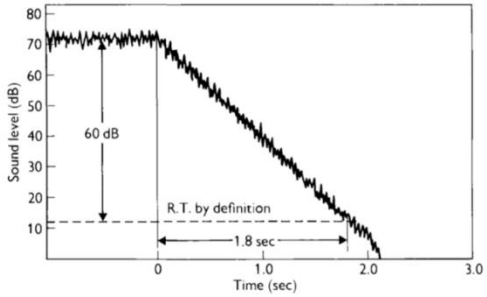
FIGURE 11-3 The length of the decay trace depends on the strength of the source and the noise level. (A) An example of a full 60-dB decay. Practical circumstances rarely allow this. (B) The slope of the limited decay is extrapolated to determine the reverberation time.

Sabinova enačba za odmevni čas v notranjih prostorih (Wallace Clement Sabine, 1868-1919)

$$RT_{60} = 0.161 \; V \; (m^3) / A \; (m^2) \; (s)$$

druga oblika: $RT_{60} = (0{,}163\ V)/ (A + 4mV)$

$$A = \Sigma \alpha_i \times S_i \quad (m^2)$$



V …….. prostornina prostora (m^3)
$A = \Sigma \alpha_i \times S_i$ ….. ekvivalentna absorbcijska površina (m^2)
α_i …….. absorbcijski koeficient določenega materiala (-)
S_i …….. absobcijska površina določenega materiala (m^2)
4mV …….. absorpcija zvoka v zraku

Eyringova formula:

$$TR_{Ey} = (0{,}163\ V)/ (-S * \ln(1- \alpha_{AV}) + 4mV) \quad (s)$$

S …… seštevek vseh površin v prostoru
α_{AV} ……srednji koeficient absorpcije zvoka vseh površin v prostoru
4mV ……. absorpcija zvoka v zraku

Idealna vrednost odmevnega časa v odvisnosti od prostornine prostora

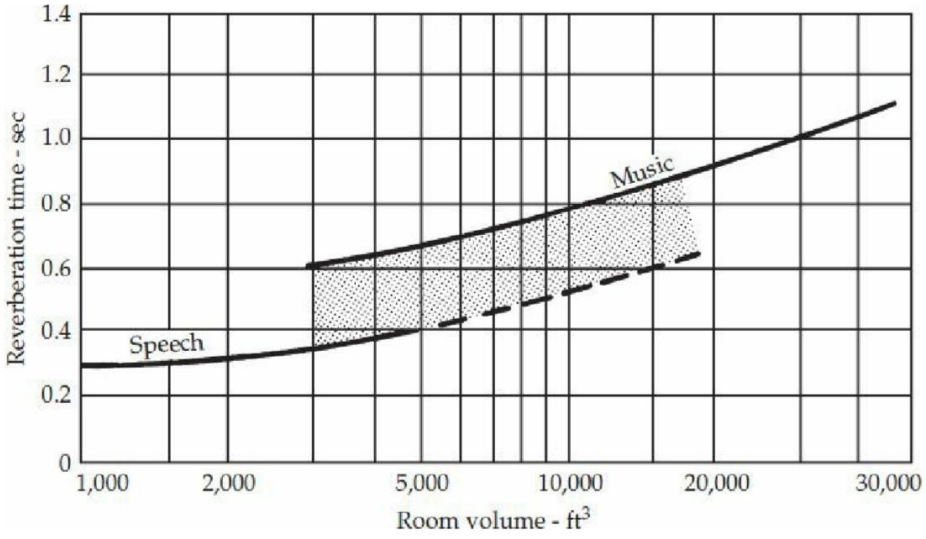
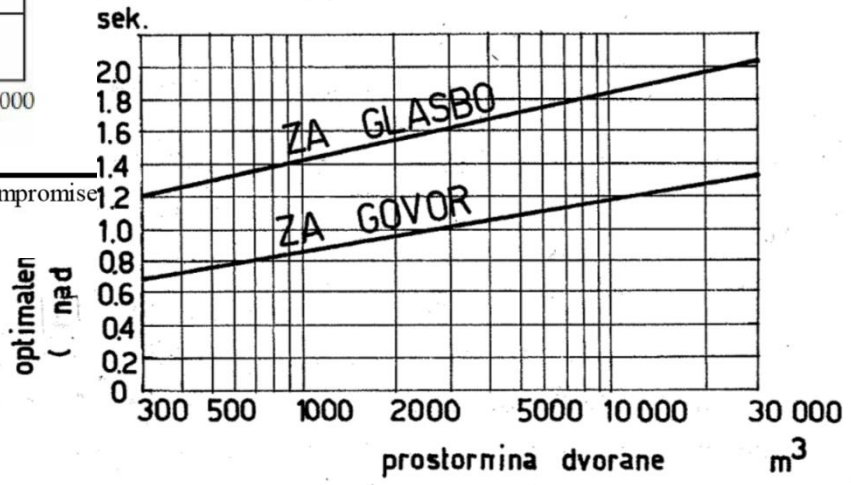
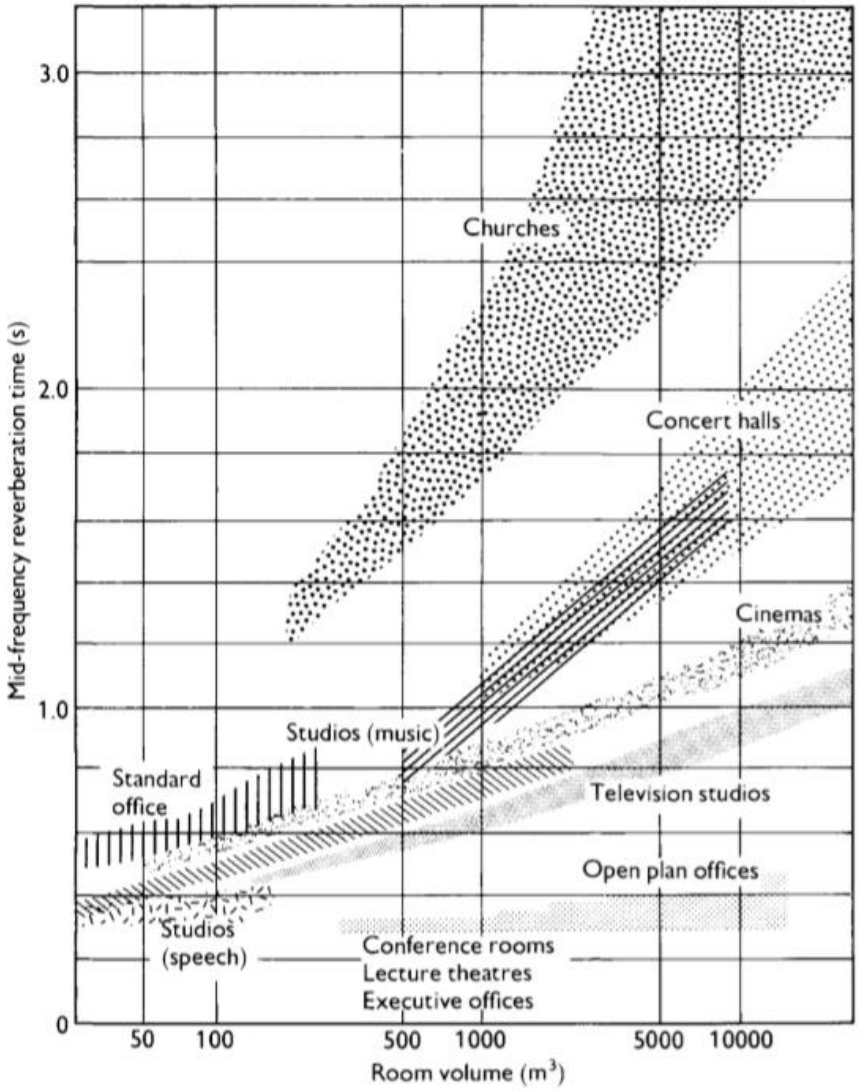
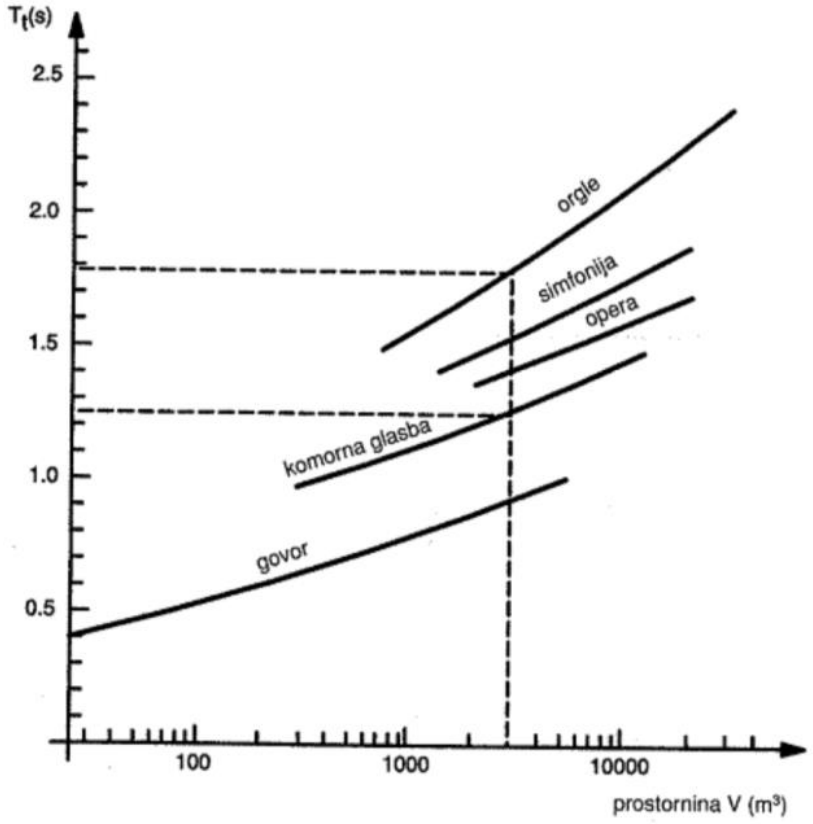


FIGURE 22-3 Suggested reverberation times for recording studios. The shaded area is a compromise region for studios in which both music and speech are recorded.



Idealna vrednost odmevnega časa v odvisnosti od prostornine prostora





Odmevni čas, v odvisnosti od prostornine in vrste glasbe [03]

Idealna vrednost odmevnega časa v odvisnosti od prostornine prostora / frekvence zvoka

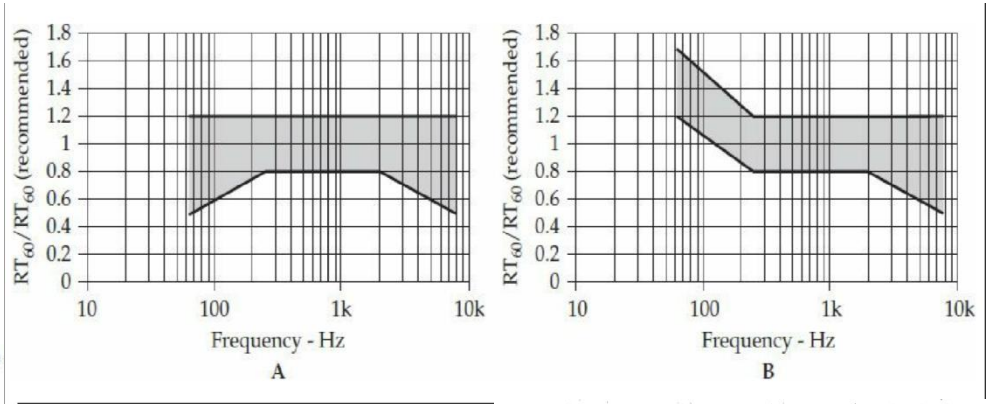
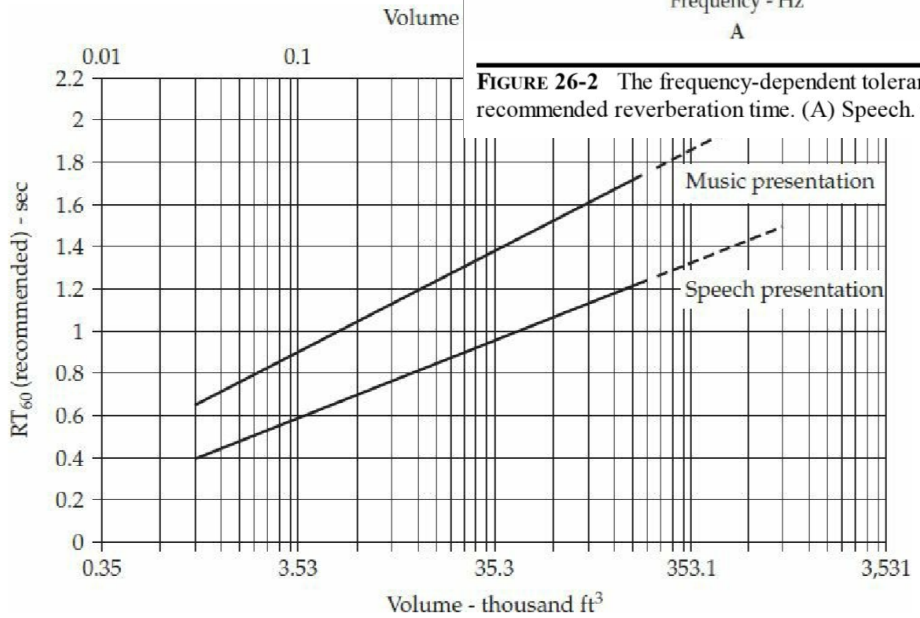
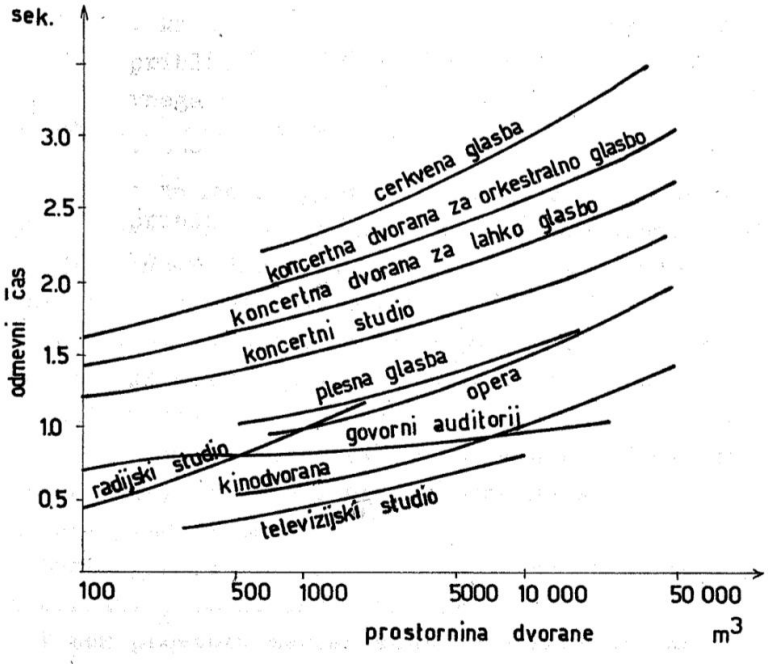


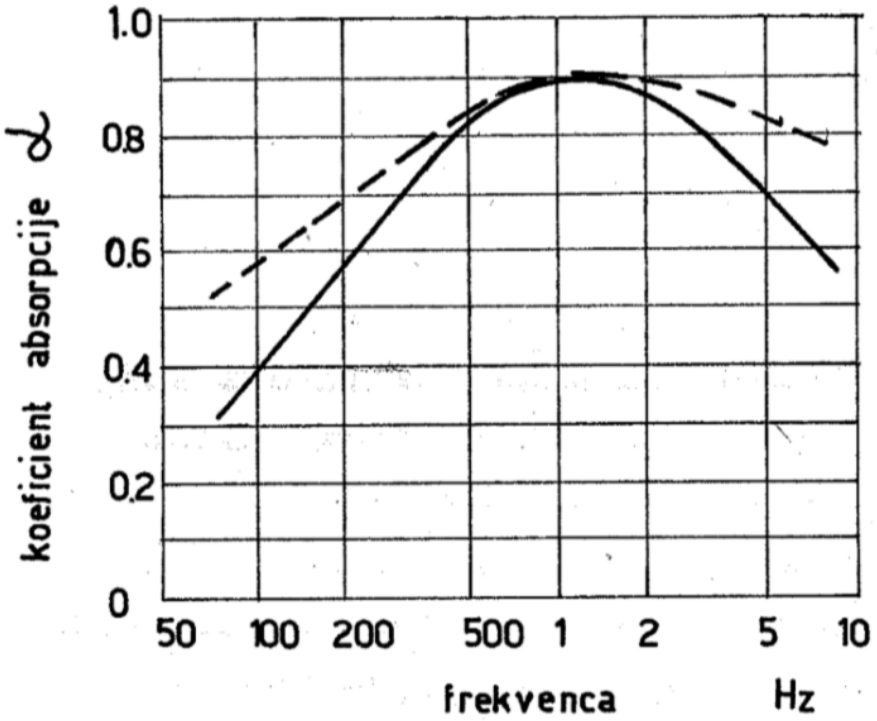
FIGURE 26-2 The frequency-dependent tolerance recommended reverberation time. (A) Speech. (B)

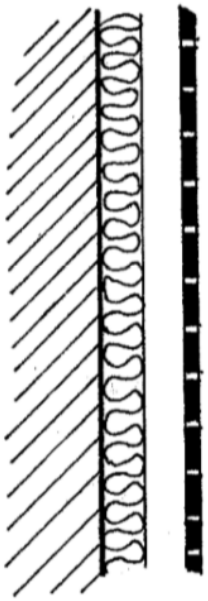


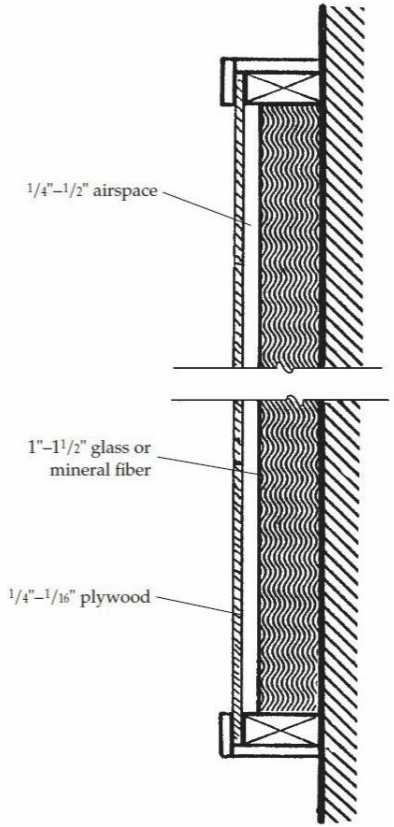
IGURE 26-1 The recommended mean reverberation time between 500 and 1,000 Hz, for speech nd music, with respect to room volume. (*Ahnert and Tennhardt.*)



Integrirani absorberji: akustične plošče, akustični paneli







Typical resonant panel absorber with wall mounting.

Odmevni čas pred in po akustičnem posegu v prostoru

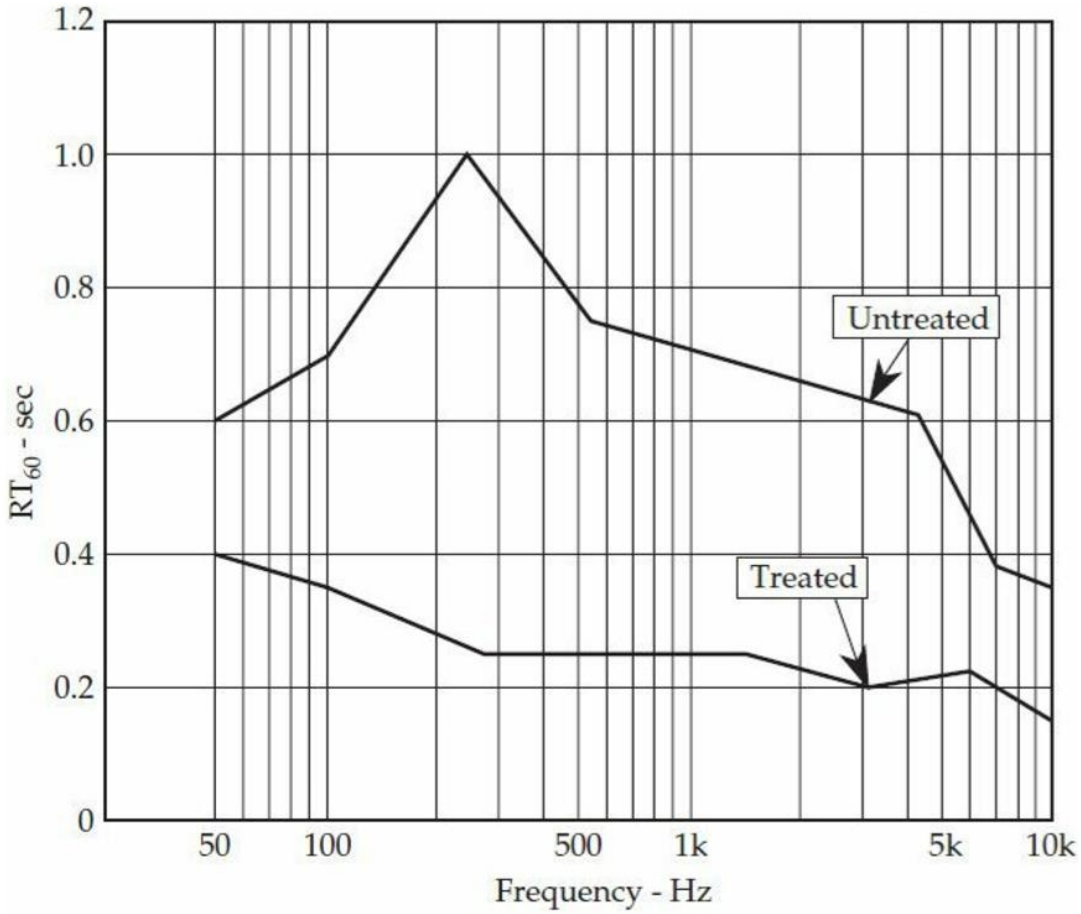
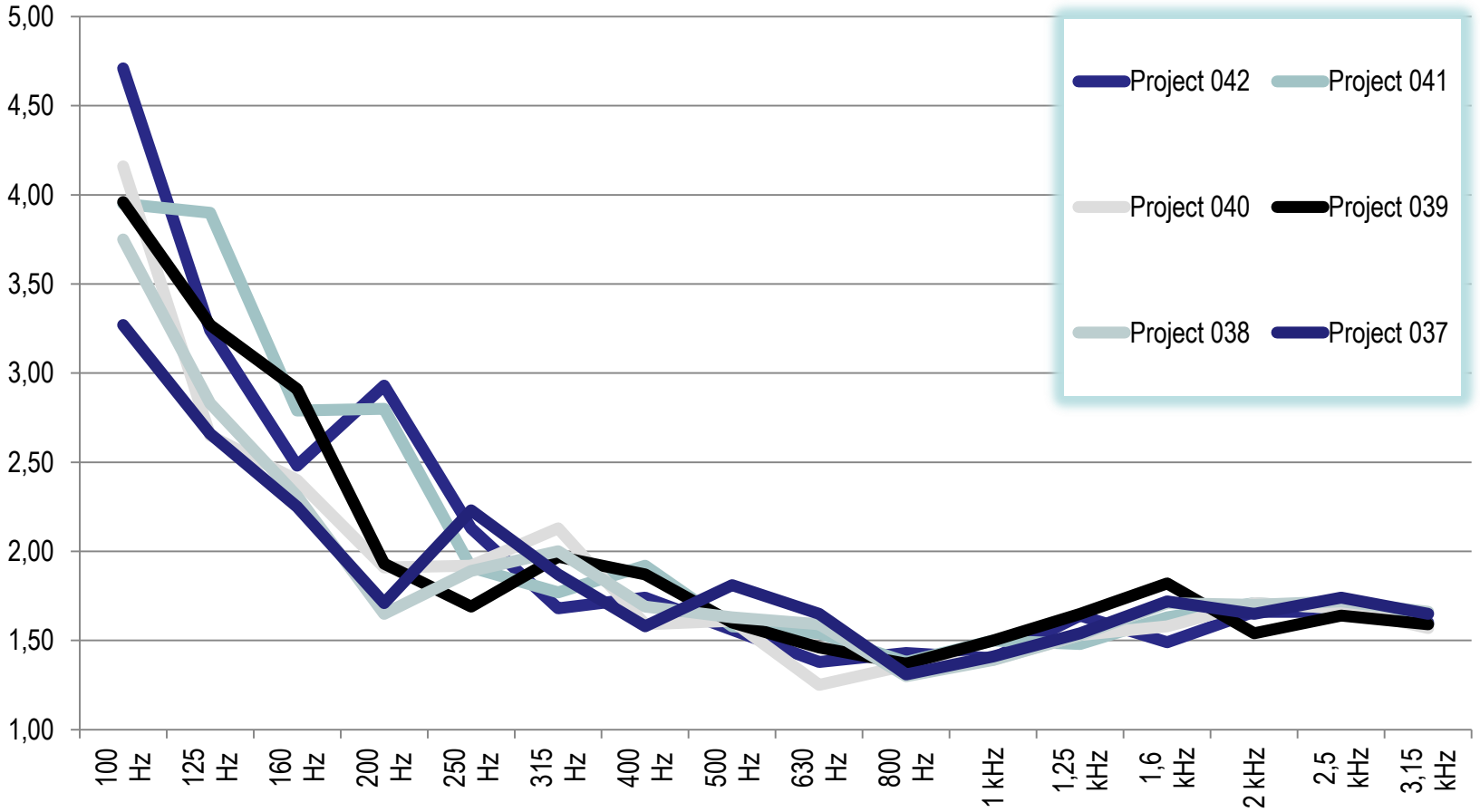


FIGURE 11-10 An example of a room's reverberation characteristic before and after room treatment. A significant rise in reverberation time in the upper bass and lower midrange is changed to a flatter characteristic with a moderate increase in reverberation time at low frequencies.

Stara stavba

Učilnica A 409 (identična učilnica A408)

Project 037, Project 038, Project 039, Project 040, Project 041 & Project 042



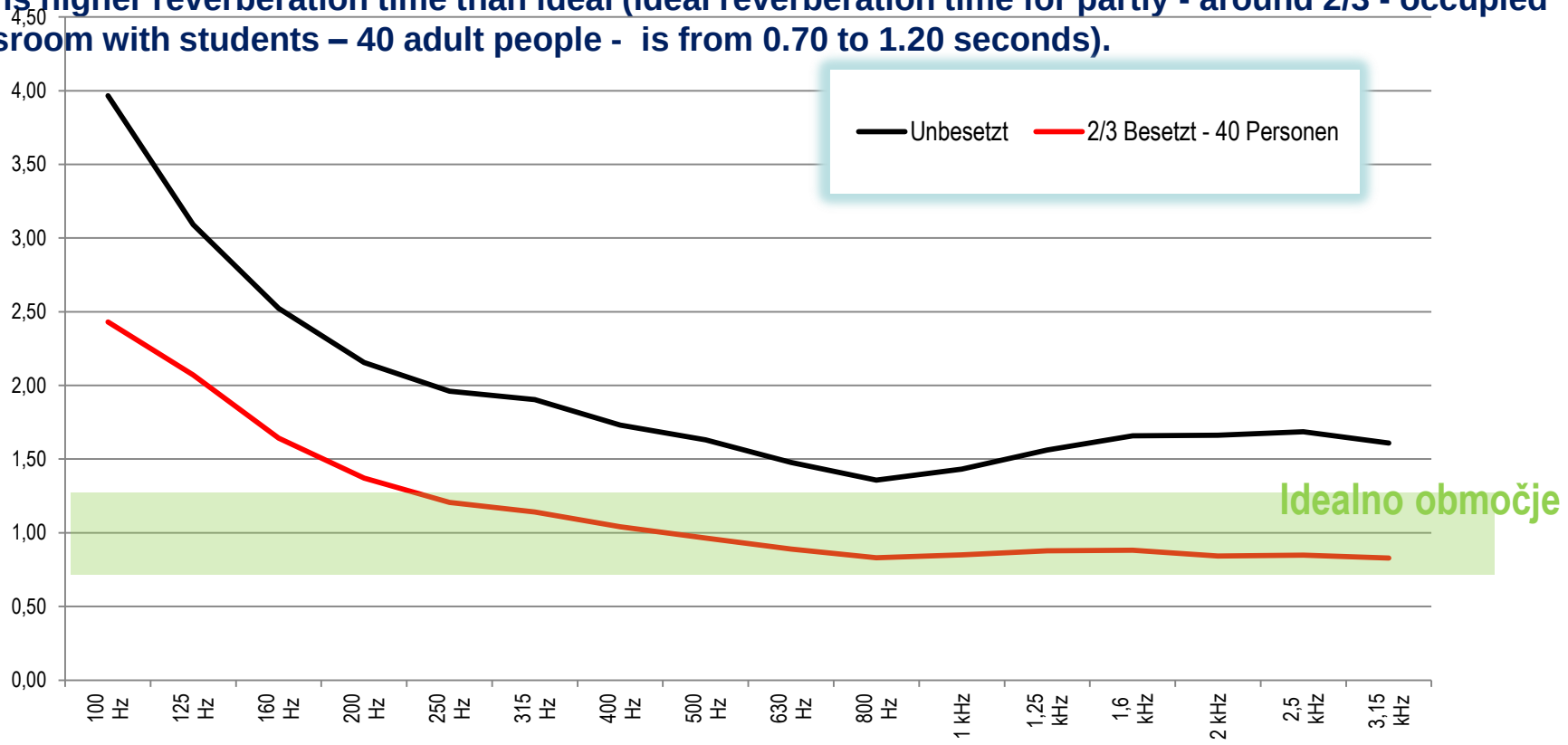
Stara stavba (okrog 1930) (Altbau A 409 und A 408)

Reverberation time in empty classroom (not occupied by students) is very long and is form minimum 1.38 up to 4.50 seconds.

Average reverberation time in speech frequencies for empty classroom is between 1.50 and 2.50 seconds.

If we compensate this reverberation time with standard DIN 18041, than is corrected reverberation time for 2/3 occupation with students, what represent approx. 40 adult people, between 0.80 and approx.. 1.50 seconds.

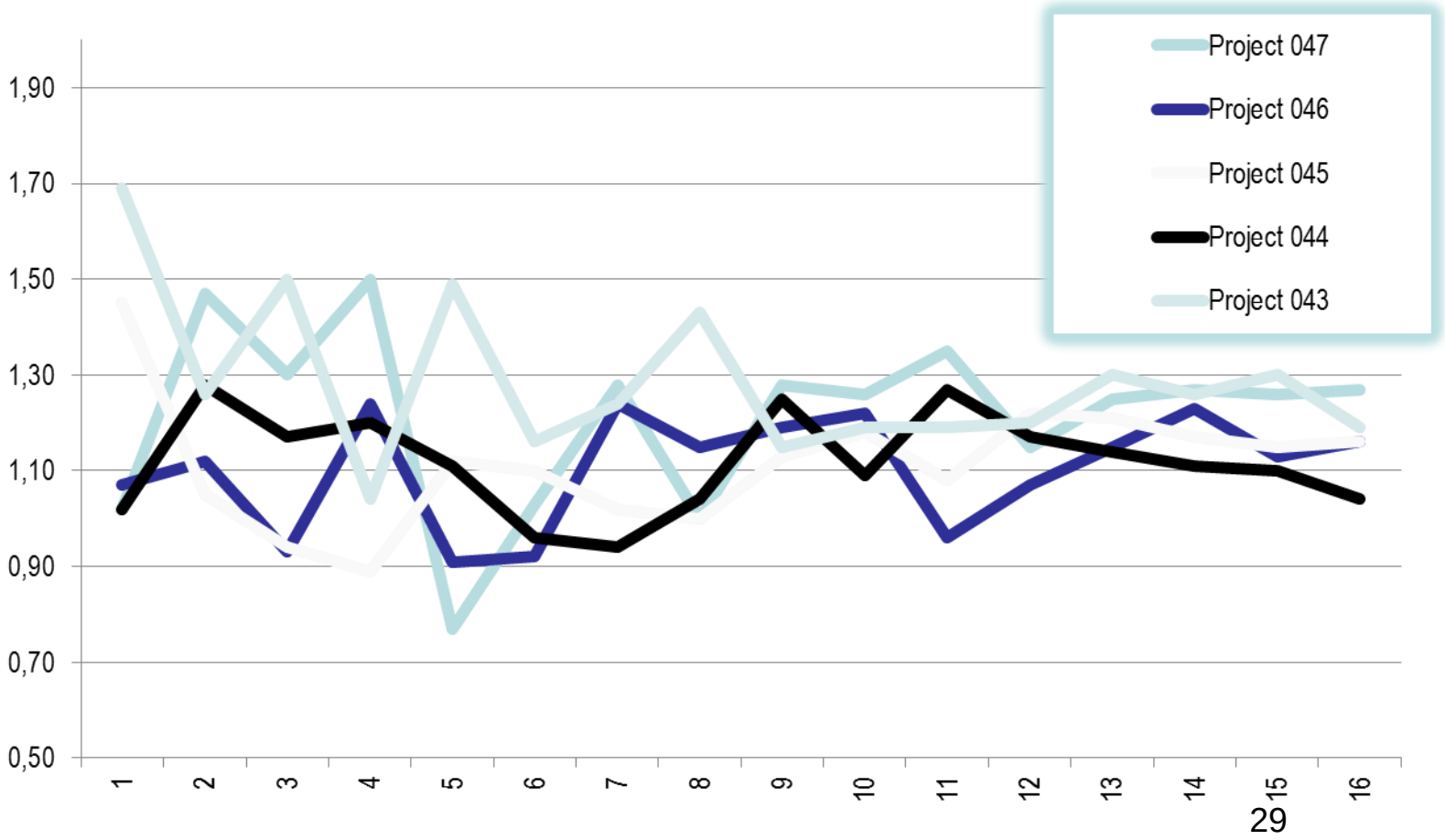
This is higher reverberation time than ideal (ideal reverberation time for partly - around 2/3 - occupied classroom with students – 40 adult people - is from 0.70 to 1.20 seconds).



Nova stavba (okrog 1985):

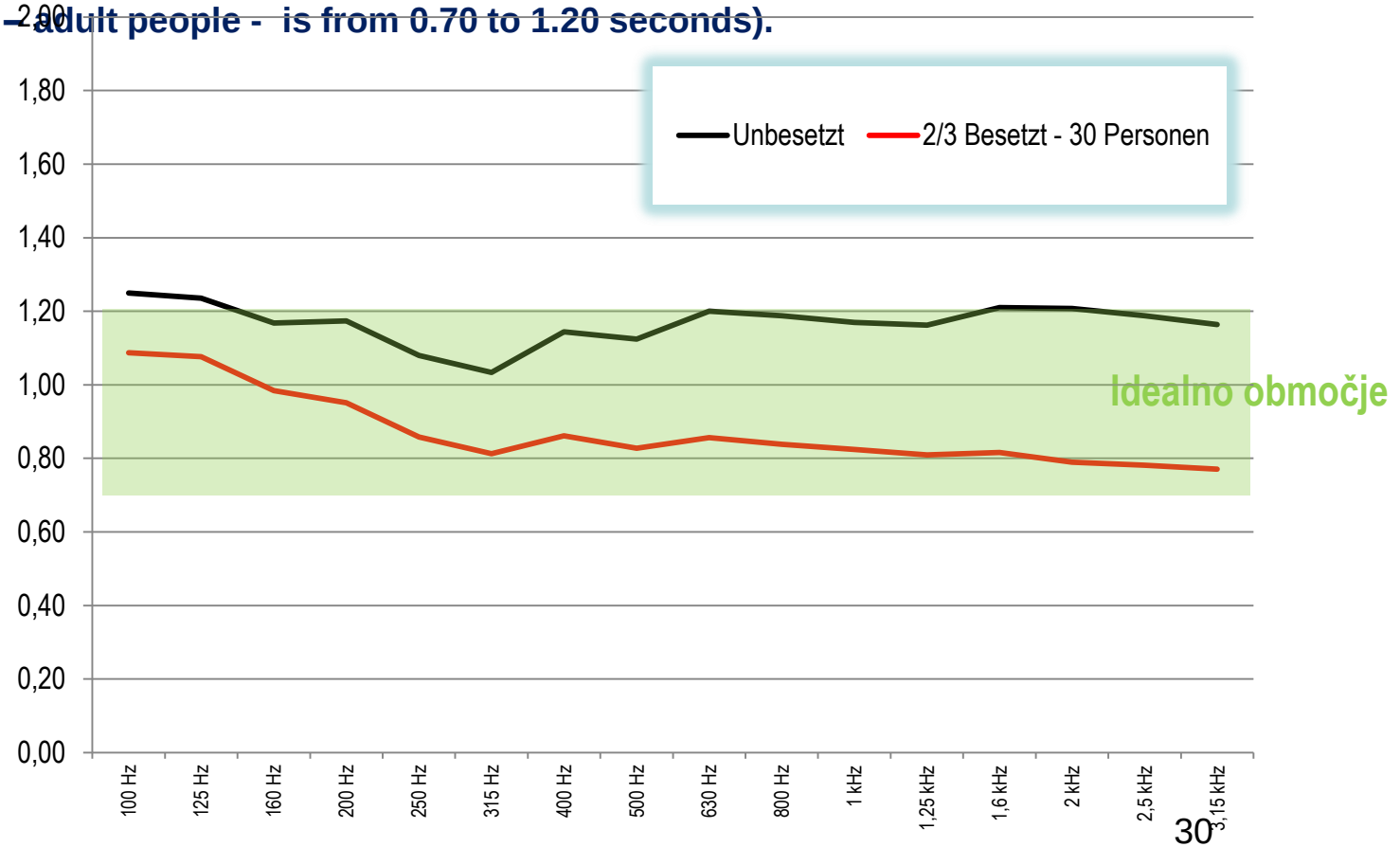
Učilnica G 3.42 - Project 045, Project 046 & Project 047

Učilnica G 3.38 – Project 043 & Project 044

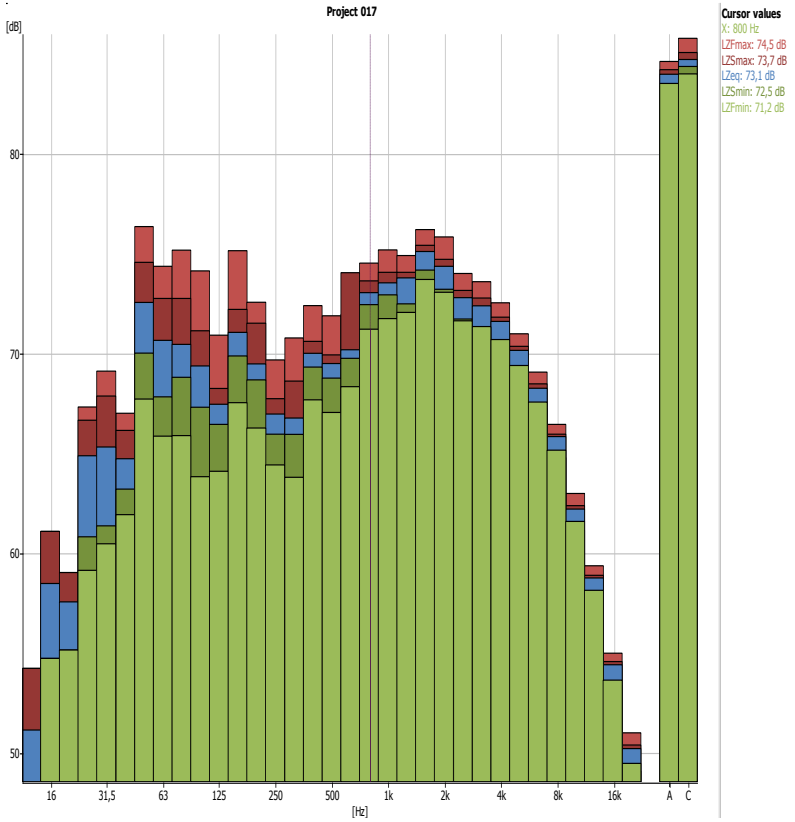


New building (G 3,38 und G 3,42):

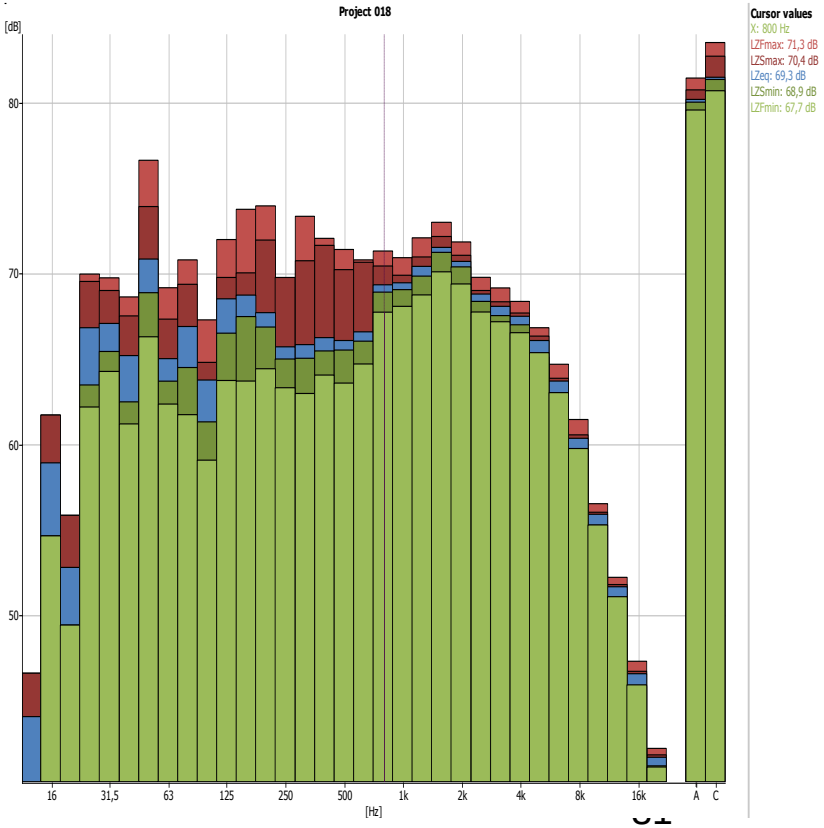
Rooms are acoustically treated with absorbers. Reverberation time in empty classroom (not occupied by students) is form minimum 0.77 up to 1.69 seconds.
Average reverberation time in speech frequencies is between 1.00 and 1.40 seconds.
If we compensate this reverberation time with standard DIN 18041, than is corrected reverberation time for 2/3 occupation with students, what represent approx. 30 adult people, between 0.80 and 1.05 seconds.
This reverberation time is as ideal (ideal reverberation time for partly - around 2/3 - occupied classroom with students – adult people - is from 0.70 to 1.20 seconds).



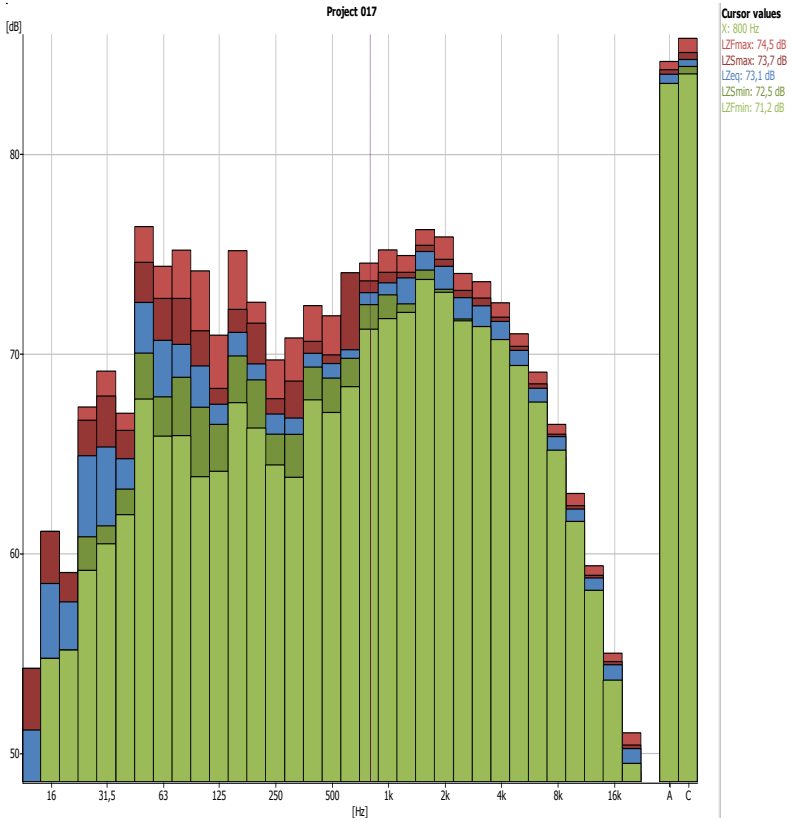
Old building
1m from source, oriented to source (74,5 dB(A))



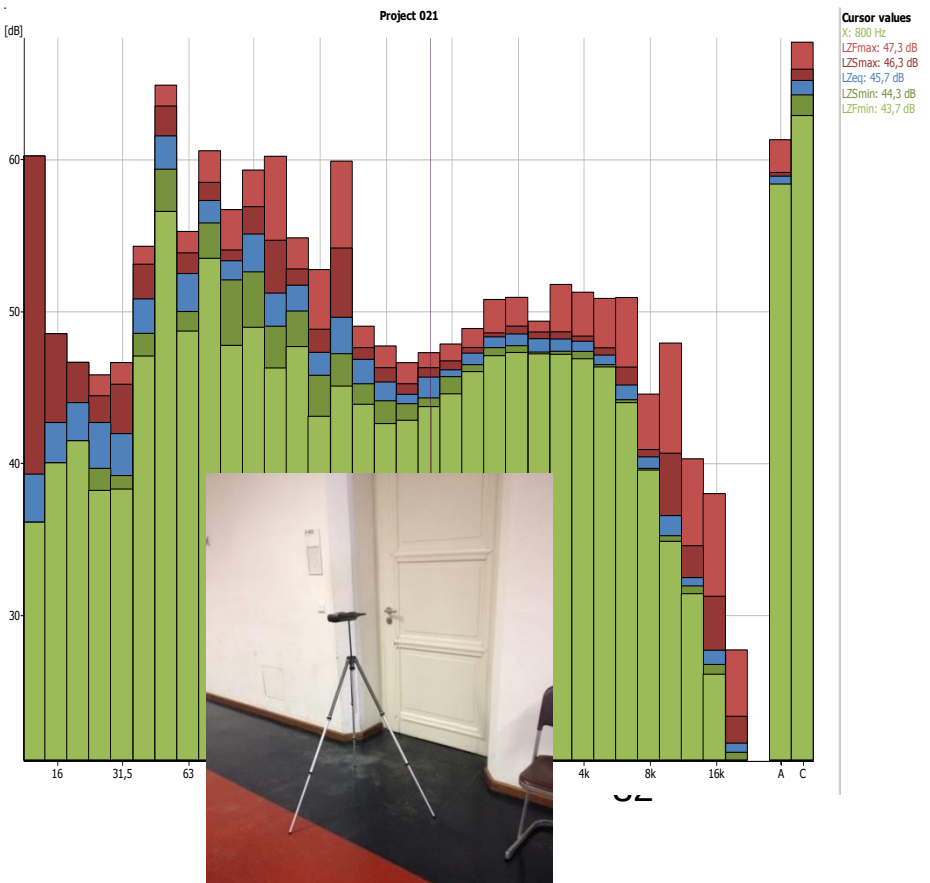
Old building
8m from source, oriented to source (3,2 dB lower)



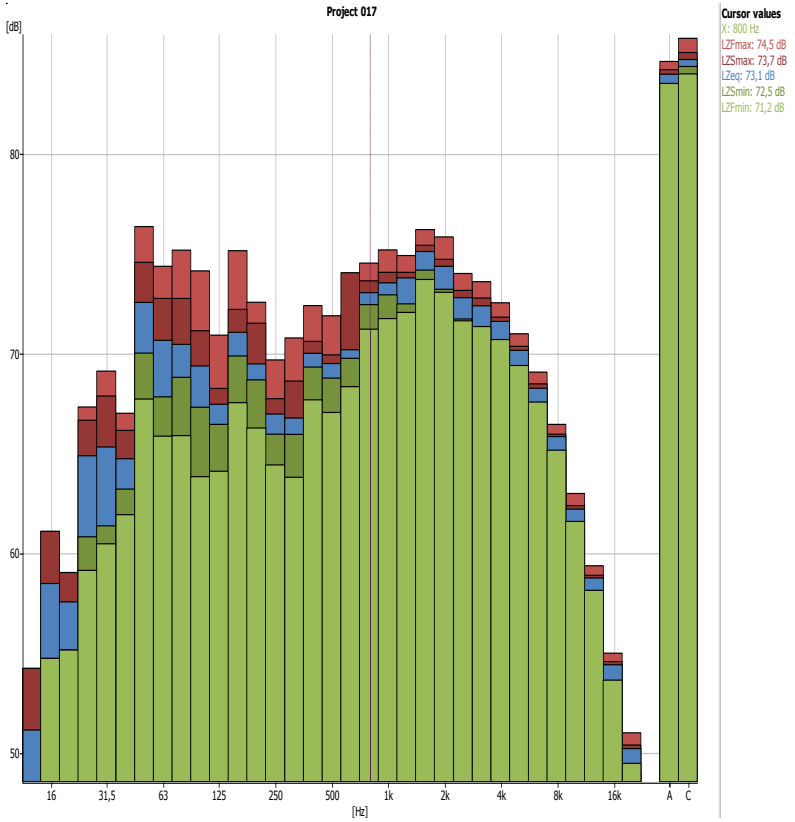
Old building
1m from source, oriented to source (74,5 dB(A))



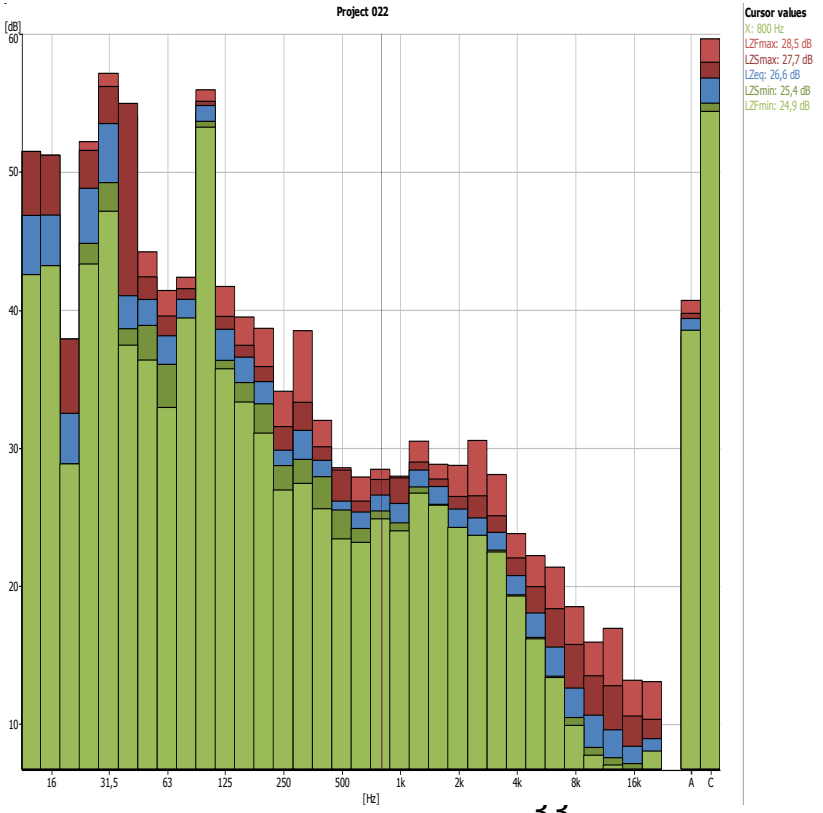
Old building
On the other side of the door, 1m from door (27,0 dB lower)



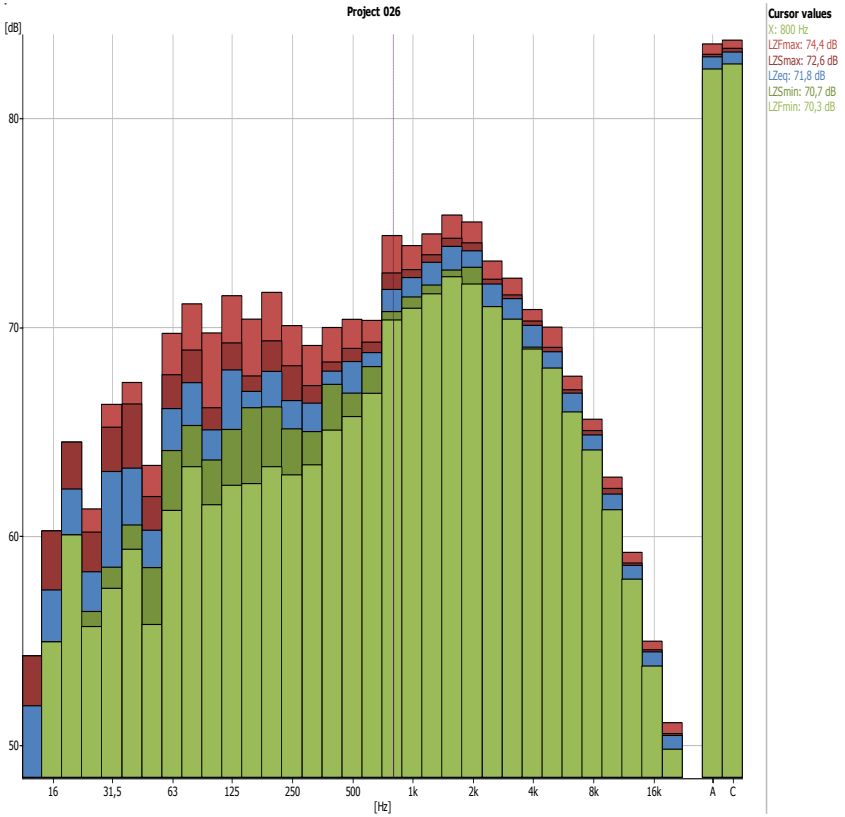
Old building
1m from source, oriented to source (74,5 dB(A))



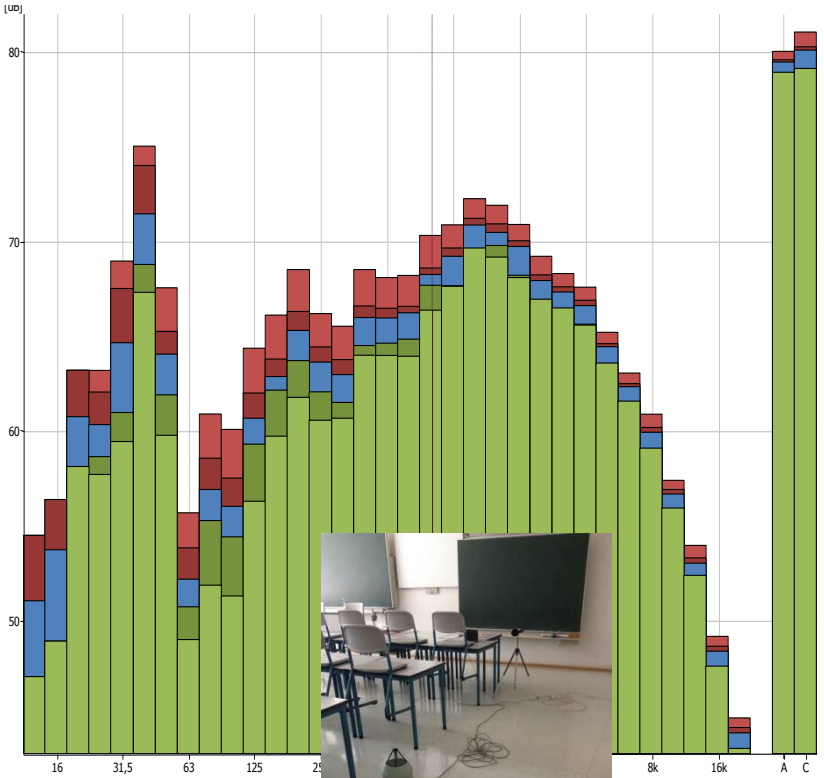
Old building
In other room (A408), 1m from wall (45,5 dB lower)



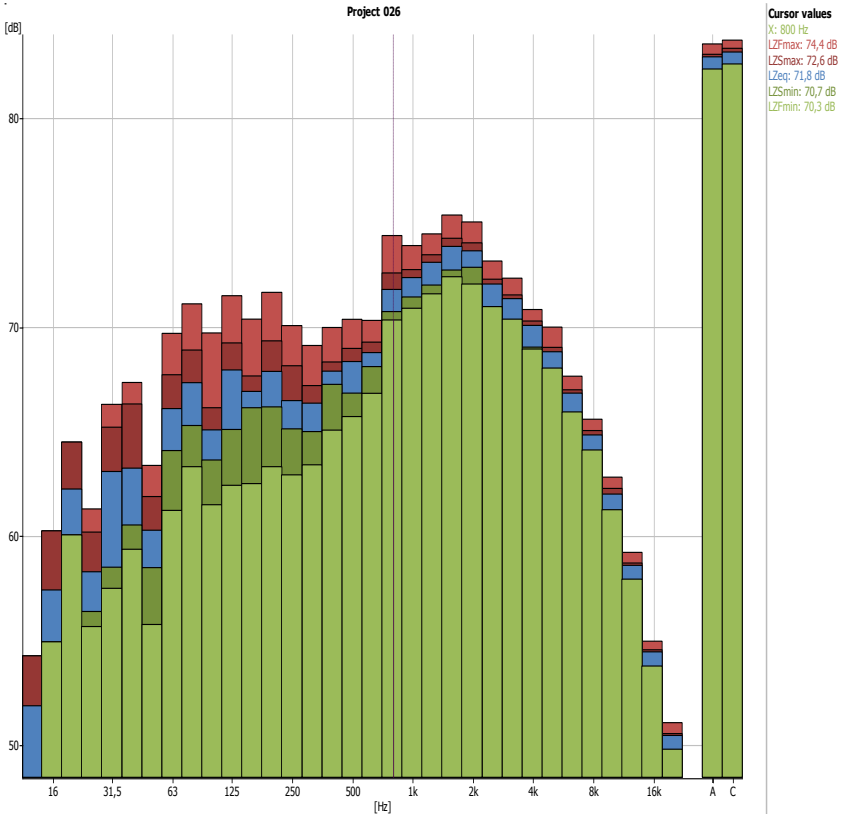
New building
1 m from source, oriented to the source (74,4 dB(A))



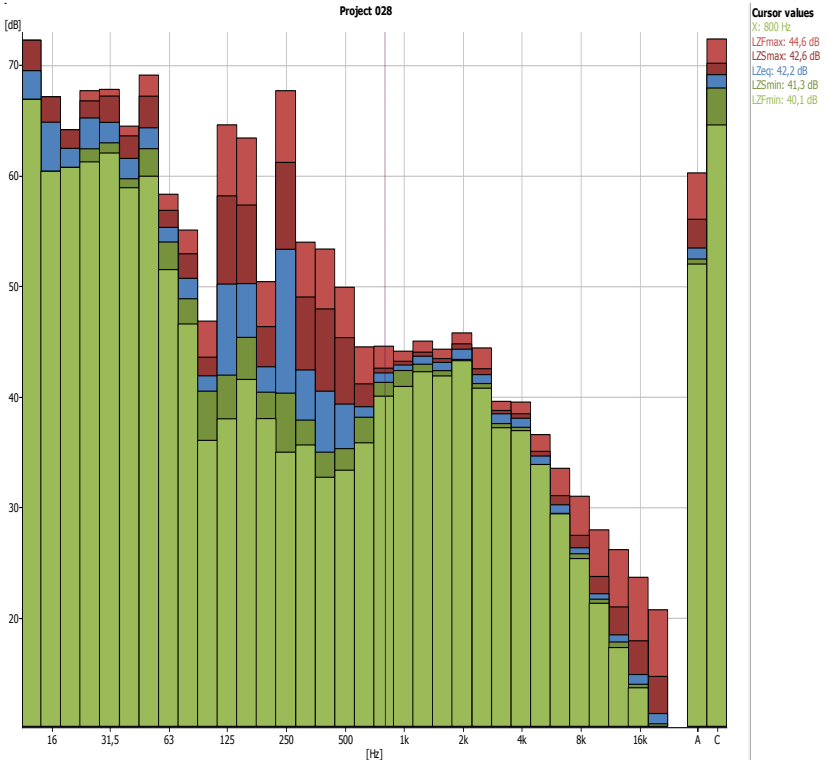
New building
6 m from source, oriented to the source (4,1 dB lower)
(old building 3,2 dB lower / 8m)



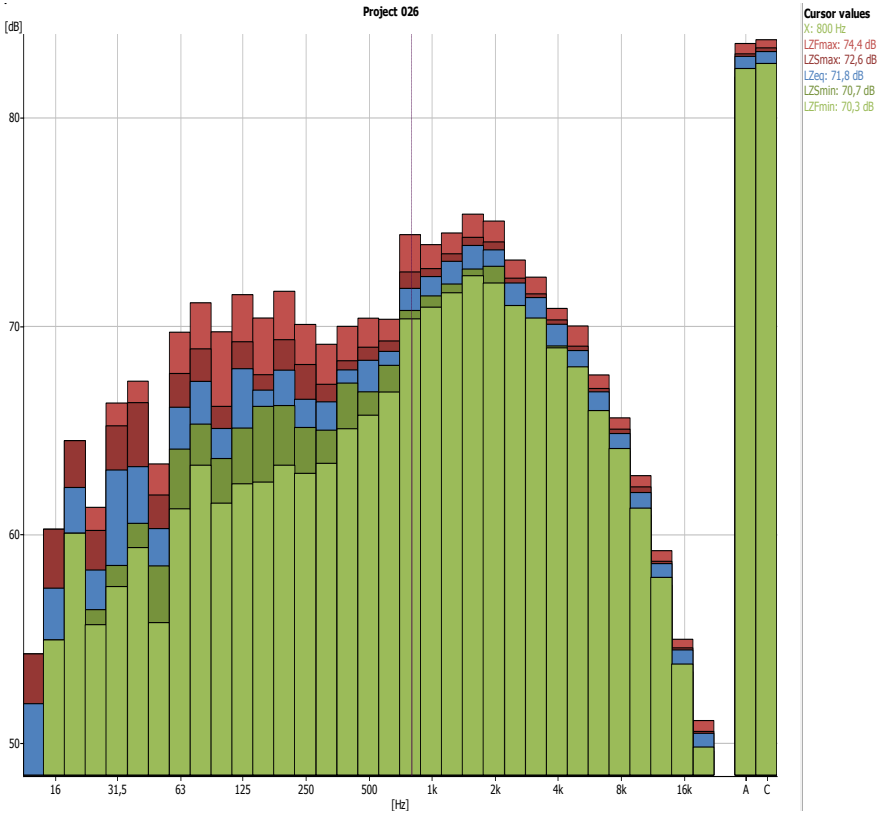
New building
1 m from source, oriented to the source (74,4 dB(A))



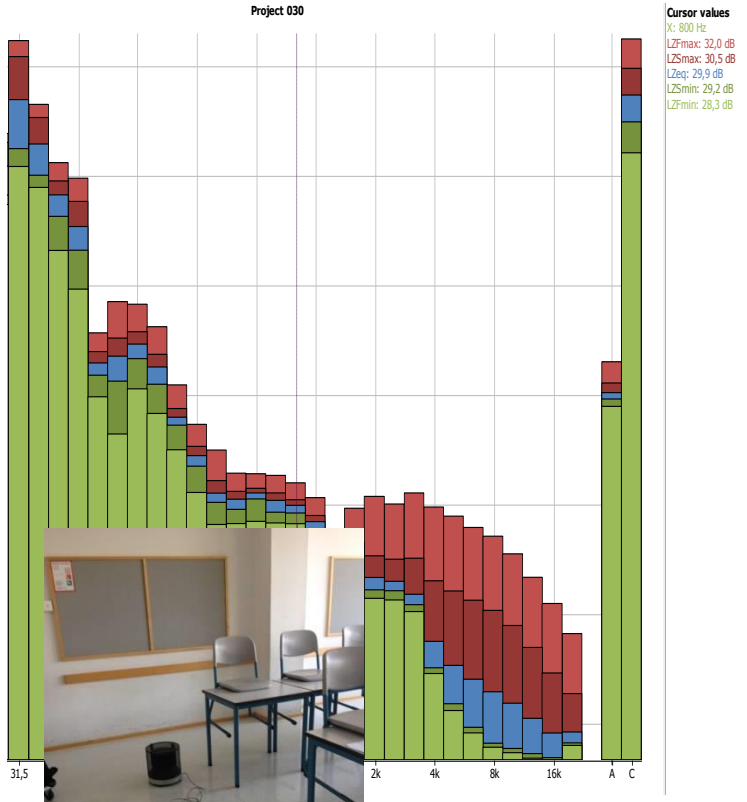
New building
On the other side of the door, 1m from door (30,0 dB lower)
(old building 27,0 dB lower)



New building
1 m form source, oriented to the source (74,4 dB(A))



New building
In another room (G3.42), 1m from the wall (42,5 dB lower)
(old building 45,5 dB lower)



REFERENCES

- Technical Guideline TSG – 1 – 005 : 2012 Protection against noise in buildings'
- SIST EN 12354-1: Buildings acoustics – Estimation of acoustic performance of buildings from the performance of elements – Part 1: Airborne sound insulation between rooms
- http://www.euro.who.int/__data/assets/pdf_file/0017/43316/E92845.pdf (obtained on 25. 7. 2016)
- Bilban, M. 1999. Medicina dela. Ljubljana. ZVD Zavod za varstvo pri delu: 605 str., diplomska naloga, 1986
- Pravilnik o zaščiti pred hrupom v stavbah. Uradni list RS št. 14/1999 (s sprem. Uradni list RS, št. 10/2012).
- M. Uršič, “Analysis of sound insulation of external envelope constructions dependent on different levels of external noise”. Graduation thesis, University of Ljubljana, Faculty of Civil and Geodetic Engineering, Ljubljana, 2015, pp. 1 - 45
- M. Uršič, M. Dovjak and R. Kunič, “Analysis of sound insulation of external envelope constructions dependent on different levels of external noise”, Gradbeni vestnik, April 2016, pp 82 - 89
- Agencija Republike Slovenije za okolje (ARSO). 2008. http://www.arso.gov.si/varstvo%20okolja/hrup/karte/ (obtained on 25. 7. 2016)
- Official Gazette of Republic Slovenia, no. 105/2005
- L. Podbelšek, “Computational analysis of sound insulation between rooms in accordance with current legislation”. Graduation thesis, University of Ljubljana, Faculty of Civil and Geodetic Engineering, Ljubljana, 2016, pp. 1 - 49
- SONITUS PROJEKT: programska oprema. Zbornica za arhitekturo in prostor slovenije.
- Hrup'13: programska oprema. Arhim d.o.o.
- URSA Fragmat Akustika 2.1.08, 2013: programska oprema. Fakulteta za elektrotehniko, Univerza v Beogradu.
- BASTIAN 2.3 - The Building Acoustics Planning System: programska oprema: DataKustik GmbH
- Čudina, M. 2014. Tehnična akustika. Merjenje, vrednotenje in zmanjševanje hrupa in vibracij. Ljubljana, Univerza v Ljubljani, Fakulteta za strojništvo: 332 str.
- Kunič Roman, Akustika stavbe, prostora in akustična izolacija, Mentor: prof.dr. Niko Seliškar, UL FGG KSKE,