5 Impact sound insulation

ELEC-E5640 - Noise Control D

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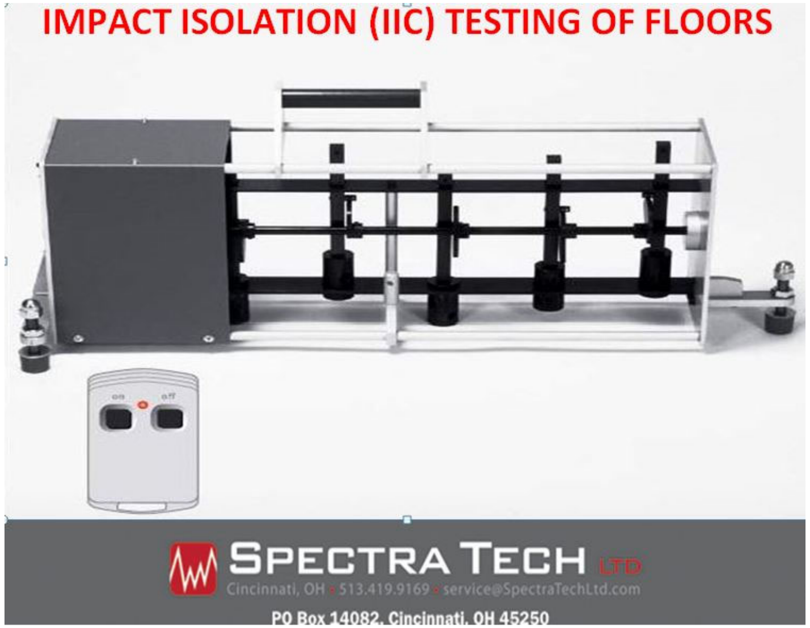
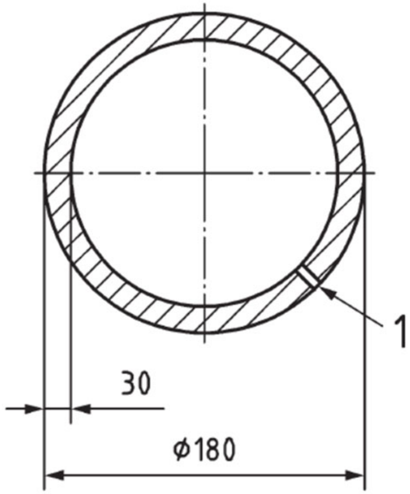
Standardized impact sound sources



Standardized tapping machine

- Hammers of m_h=0.5 kg are dropped to the floor with a frequency of f_i=10 Hz.
- Dropping height is h=0.04 m
- Measured quantity is equivalent SPL, $\mathbf{L_n}$.



Rion Impact Ball YI-01

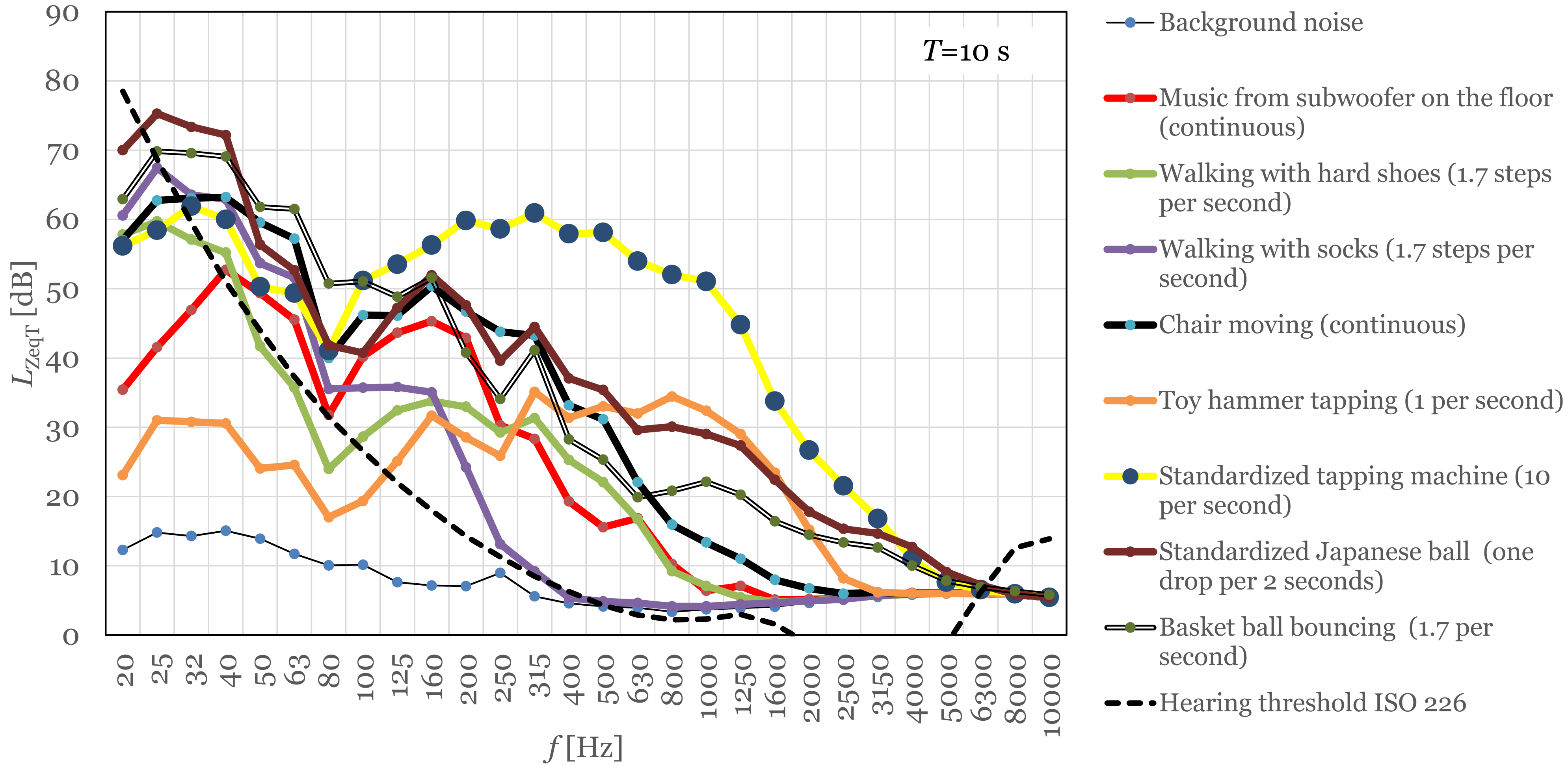
Standardized rubber ball

- 2.5 kg ball, no bouncing
- 1000 mm dropping height produces a stable force of 1500 N.
- Field measurement standard ISO 16283-2 involves an optional method for the Japanese ball but it is considered in Finnish regulations.
- Measured quantity is spatially averaged Fast-weighted maximum SPL, $\mathbf{L_{iF,max}}$.

SPLs of impact sounds in an apartment

FLOOR $L'_{n,w}$ 53 dB

- 160 mm steel-reinforced concrete
- 30 mm screed filler
- vinyl carpet ΔL_W=21 dB



A-weighted
SPLs of impact sounds in an apartment

FLOOR $L'_{n,w}$ 53 dB
- 160 mm steel-reinforced concrete
- 30 mm screed filler
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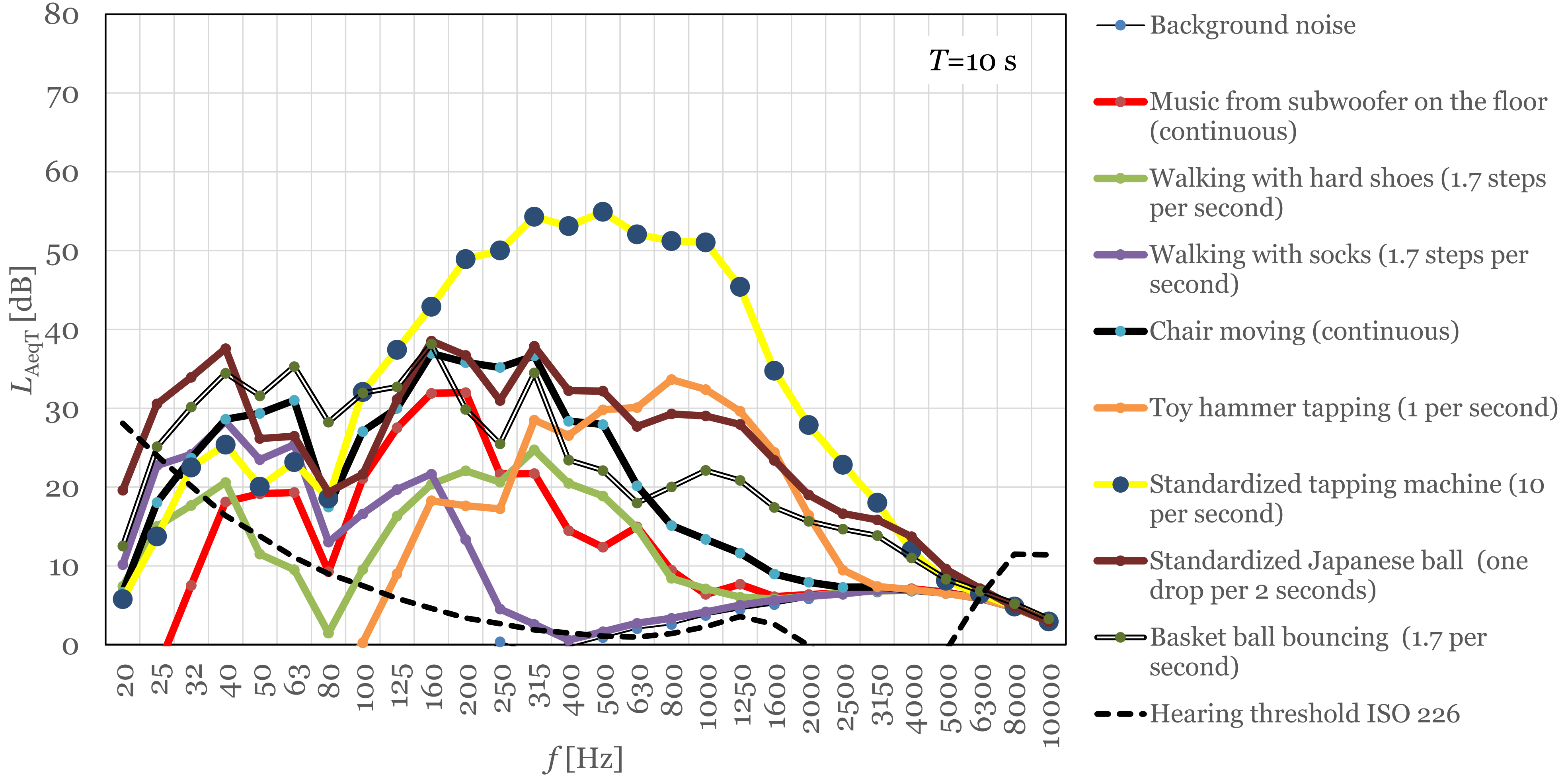


Old Finnish building code C1:1998
valid until the end of 2017

- $L'_{n,w}$ = 53 dB shall not be exceeded between dwellings
- $L'_{n,w}$ = 63 dB shall not be exceeded from stairway to dwelling

- Limited to range 100-3150 Hz

New Finnish building code

- Decree 796/2017 of Ministry of Environment
- Weighted standardized impact SPL ($L'_{nT,w} + C_{I,50\text{-}2500}$)

Room type	**Largest allowed $L'_{nT,w}$ + $C_{I,50\text{-}2500}$ [dB]**
Between residential dwellings and between accommodation rooms	53
From stairway to abovementioned spaces	63

Room type	**Largest recommended $L'_{nT,w}$ + $C_{I,50\text{-}2500}$ [dB]**
Between floors in education buildings	63
From handcraft education rooms to surrounding spaces	49
From music education rooms to surrounding spaces	46
Between floors in hospital, health care center etc.	63
From physical education rooms to surrounding spaces	46
Between floors in offices	63

SFS 5907:2004

Space	Class A $L'_{n,w} + C_{I,50\text{-}2500}$	Class B $L'_{n,w} + C_{I,50\text{-}2500}$	Class C $L'_{n,w}$	Class D $L'_{n,w}$
From a commercial space, office, restaurant, or other noisy space within the building, including a garage, to an apartment	43	43	49	49
From a night-club, dance restaurant or other similar space within the building to an apartment	33	38	43	43
From the spaces surrounding an apartment to an apartment or a kitchen in general [1), 2)]	43	49	53	63
From an exit for another apartment to an apartment	49	53	63	68
From spaces in the apartment to at least one room within the apartment	58	63	-	-

[1)] Use of the spectrum adaptation term $C_{I,50\text{-}2500}$ is recommended also in class C.
[2)] The requirement does not apply to measurements from service or storage spaces or similar which are used only occasionally, or to measurements from small WC, toilet or sauna spaces belonging to the apartment. Disturbing noise possibly caused in these spaces and reaching the apartment must be taken into consideration in the planning in such a way that good sound conditions are still achieved.

- Standard involves guidelines and ABCD classifications for several building types such as apartment buildings, schools, offices and health care
- Class C corresponds to the regulated values

Impact sound pressure levels

- **Normalized** impact SPL produced by tapping machine L_n in the receiving room:

$$L_n = L_2 + 10\lg\frac{A_2}{A_0} \quad [dB]$$

  - L_2 [dB] is the structure-borne SPL caused by the tapping machine in receiving room
    - Background noise level corrected
  - A_2 [m^2] is the absorption area in the receiving room
  - A_0=10 m^2 is the normalized absorption area
- Normalized value is used in laboratory tests also in the future.
- Normalized value is used in in Finland in buildings permitted before 1.1.2018

- **Standardized** impact SPL produced by tapping machine L'_n in the receiving room:

$$L'_{n,T} = L_2 + 10\lg\frac{T_2}{T_0} \quad [dB]$$

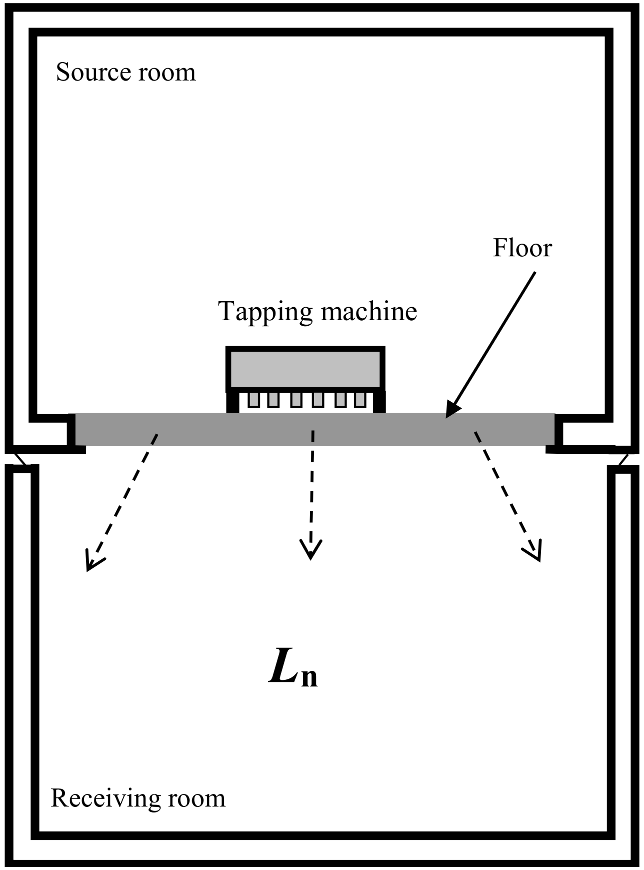
  - L_2 [dB] is the the structure-borne SPL caused by the tapping machine in the receiving room
  - T_2 [m^2] is the reverberation time in the receiving room
  - T_0=0.5 s is the standardized reverberation time
- Standardized value is applied in Finland in buildings permitted after 31.12.2017.

ISO 10140-3-2010

Impact sound pressure level

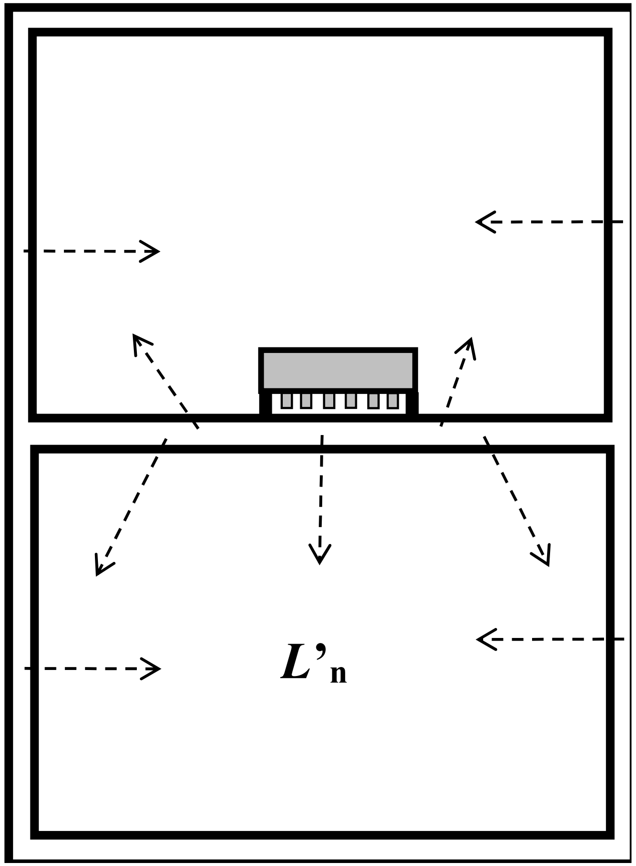
- Laboratory tests are always conducted in vertical direction
- Field measurements are conducted also in horizontal direction or even from down to up
- Frequency-dependent values are expressed by *single-number quantities*:
  - Field: $L'_{n,w}$
  - Lab: $L_{n,w}$
- Laboratory values can be different than field values (L_n, L'_n) due to different flanking transmission

LABORATORY: Rooms are mechanically detached from each other



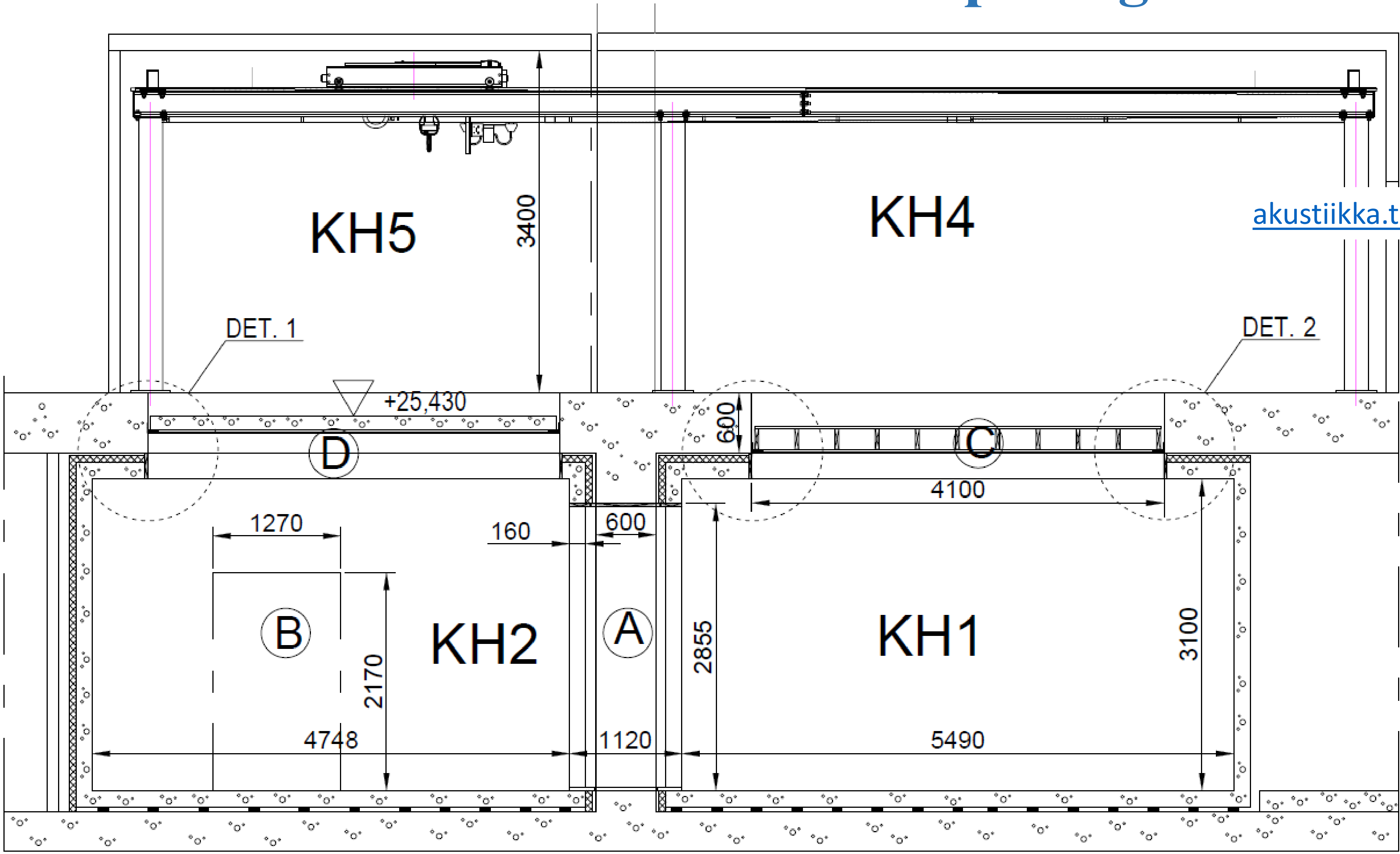
Laboratory measurements: ISO 10140

REAL BUILDING: Rooms are mechanically connected to each other



Field measurements: ISO 16283-2

Acoustics Lab in Turku: Floor test openings C & D



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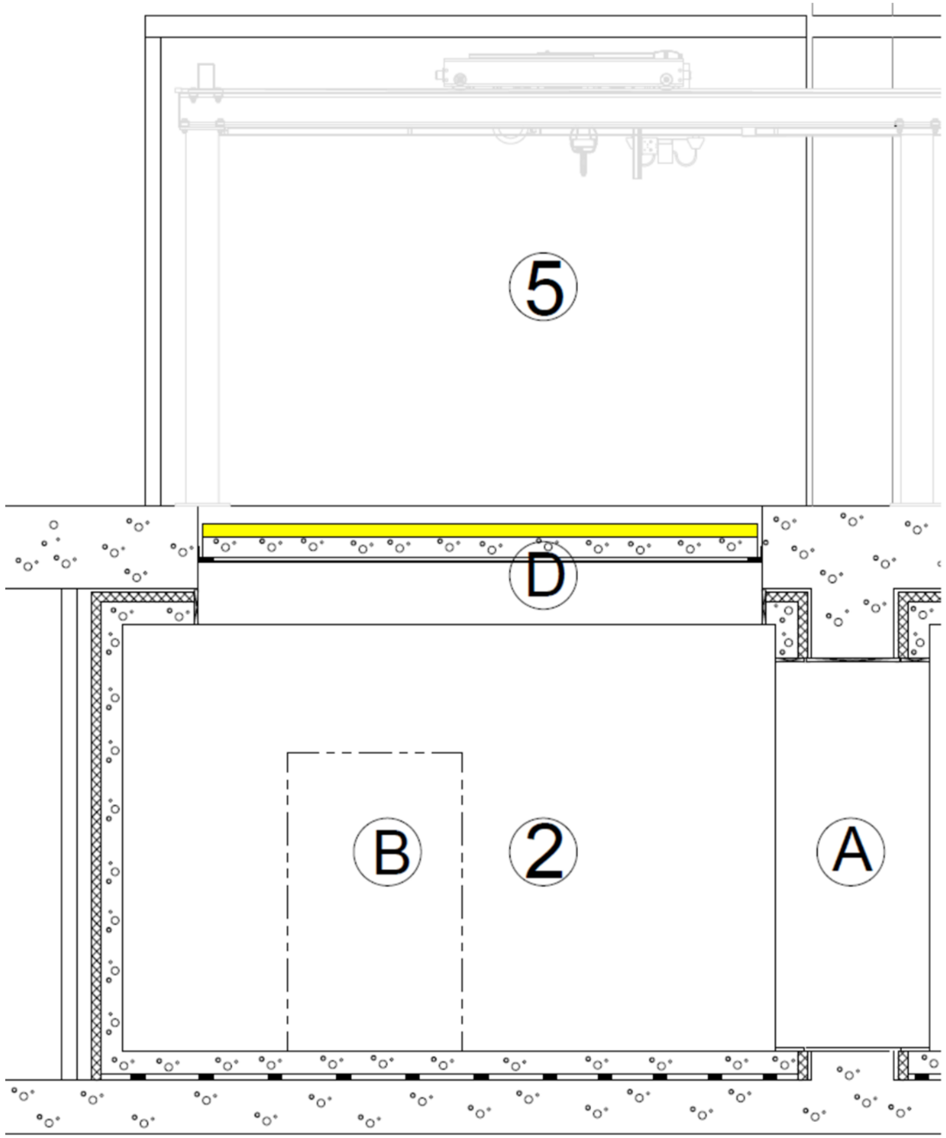
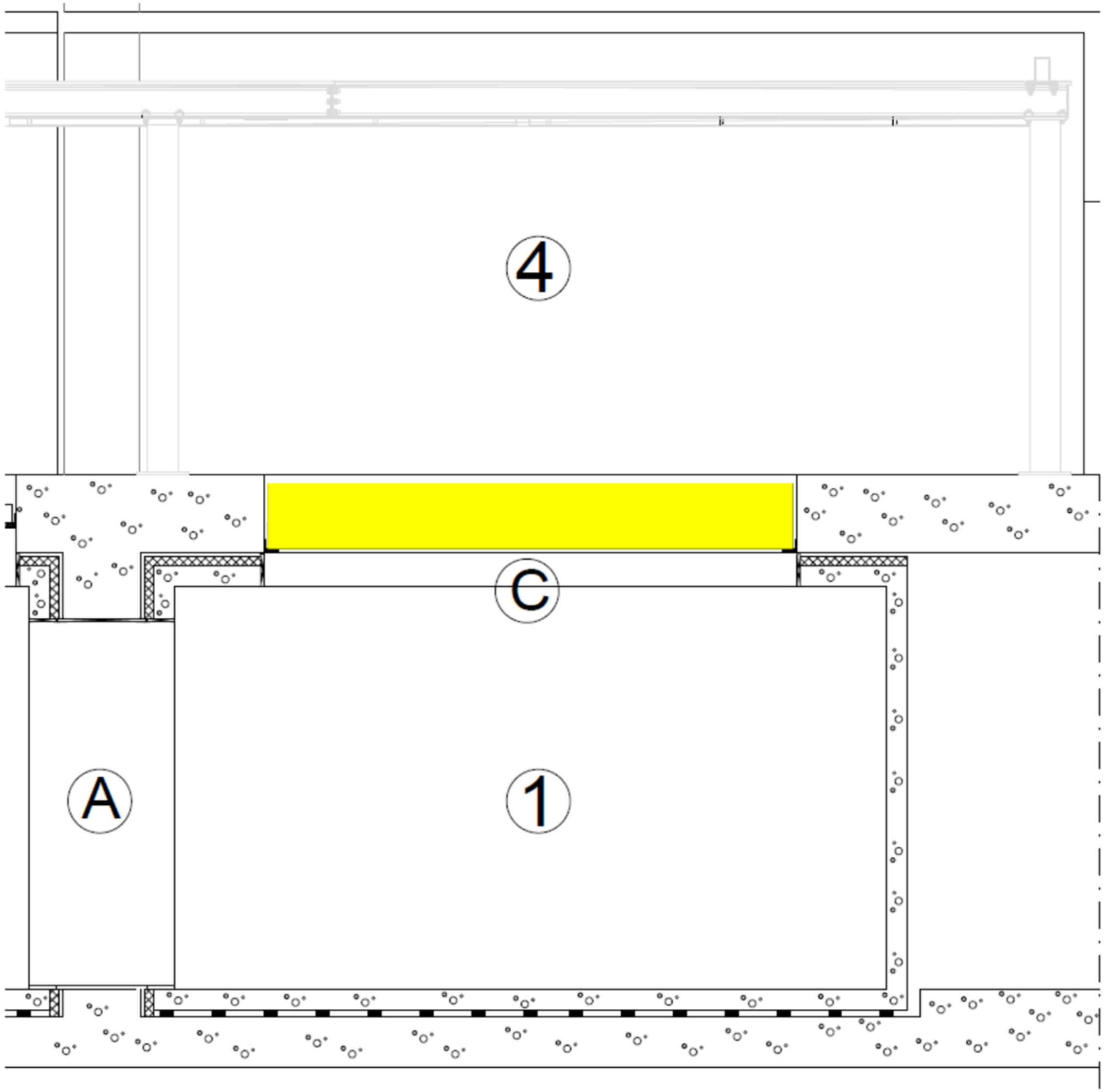
Acoustics Lab in Turku: Floor coverings

- Test opening D includes a standard 160 mm concrete slab
- Enables the determination of the weighted reduction of impact sound pressure level ΔL_w
  - laminate, parquet, vinyl
  - floating floors
  - Installation floors
- Specimen area 10 m^2
- Max. thickness 250 mm



Acoustics Lab in Turku: Floors

- Impact sound pressure level of floors is tested in opening C
  - wooden floors
  - steel floors
  - hybrid floors
  - ceilings
- Test opening C
  - includes one load-bearing wooden construction
- Specimen area 10 m^2
- Max. thickness 600 mm
- Up to 400 kg/m^2
- Airborne sound insulation is possible with the same installation



Single-number quantity $L_{n,w}$+$C_{I,50\text{-}2500}$

Weighted impact SPL $L_{n,w}$ is a single-number quantity globally used to describe the performance. It is determined from measured L_n values within 100-3150 Hz. Vertical location of reference curve Ref depends on the value that is given to the anchor frequency 500 Hz: as small value as possible is given to 500 Hz but the sum of unfavorable deviations must be at most 32.0 dB. Unfavorable deviation means that measured value is above the reference curve. With guess 42 dB reference curve is positioned to Ref42. Unfavorable deviations take place within 100-200 Hz. Since their sum is under 32.0 dB, the result $L_{n,w}$ = 42 dB. **$L'_{n,T,w}$** is calculated with the same method. Negative $C_{I,50\text{-}2500}$ values are forced to 0 dB.

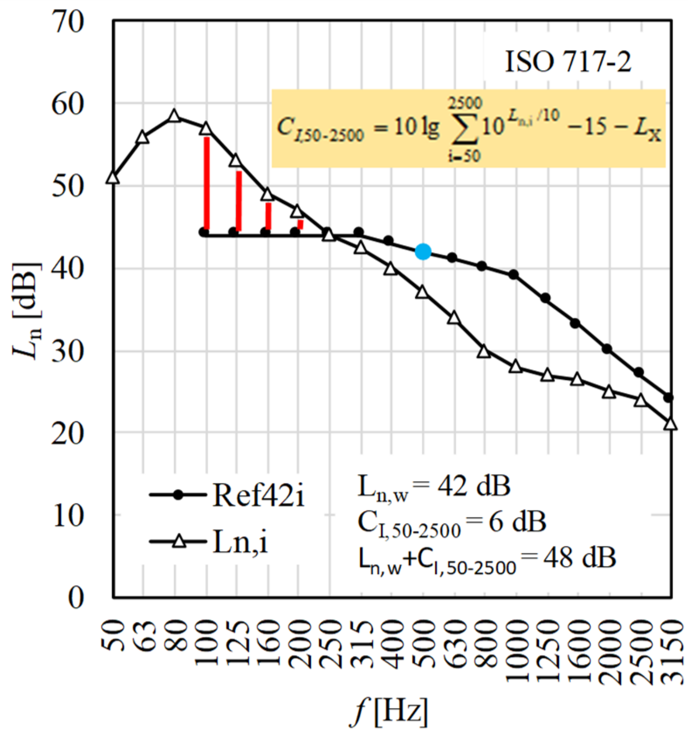
f_i	$L_{n,i}$ [dB]	Ref_i [dB]	$Ref42_i$ [dB]	Dev_i [dB]	$10^{L_{n,i}/10}$
50	51				125893
63	56				398107
80	58.5				707946
100	57.0	$L_{n,w}+2$	44	**13.0**	501187
125	53.0	$L_{n,w}+2$	44	**9.0**	199526
160	49.0	$L_{n,w}+2$	44	**5.0**	79433
200	47.0	$L_{n,w}+2$	44	**3.0**	50119
250	44.0	$L_{n,w}+2$	44	0.0	25119
315	42.5	$L_{n,w}+2$	44	0.0	17783
400	40.0	$L_{n,w}+1$	43	0.0	10000
500	37.0	$\boldsymbol{L_{n,w}}$	42	0.0	5012
630	34.0	$L_{n,w}-1$	41	0.0	2512
800	30.0	$L_{n,w}-2$	40	0.0	1000
1000	28.0	$L_{n,w}-3$	39	0.0	631
1250	27.0	$L_{n,w}-6$	36	0.0	501
1600	26.5	$L_{n,w}-9$	33	0.0	447
2000	25.0	$L_{n,w}-12$	30	0.0	316
2500	24.0	$L_{n,w}-15$	27	0.0	251
3150	21.0	$L_{n,w}-18$	24	0.0	

L_n: Measurement result

Ref: Reference curve (fixed shape, vertical position varies)

Ref45: Reference curve at position 45 dB (500 Hz value is the **anchor**)

Dev: Unfavorable deviation: Max(0; $Ref45_i$ - $L_{n,i}$)



Sum of unfavorable deviations Dev_i:

30.0 dB Highest allowed value is 32.0 dB.

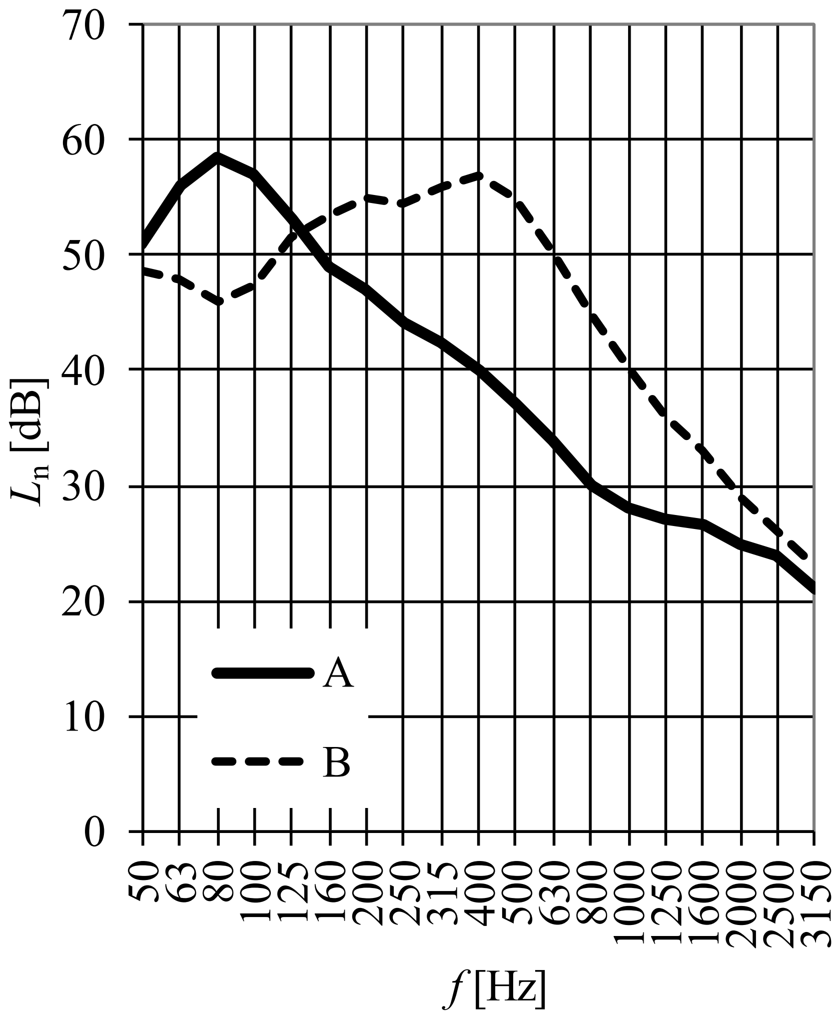
$S=\Sigma[10^{L_{n,i}/10}]=$ 2125782

$L_{n,sum}=10*\log_{10}(S)$ 63

$C_{I,50\text{-}2500}=L_{n,sum}$ - 15 - $L_{n,w}$= **6**

Spectrum adaptation term $C_{I,50\text{-}2500}$

- A and B represent two typical floor constructions
- They are and also sound acoustically very different due to different resonance frequency f_0 and related decrement in impact SPL



	A	B
$L'_{n,w}$	42 dB	49 dB
$C_{I,50\text{-}2500}$	6 dB	0 dB
$L'_{n,w}+C_{I,50\text{-}2500}$	48 dB	49 dB
f_0	80 Hz	400 Hz

A

steel reinforced concrete 300 mm
wool 30 mm
gypsum 15 mm
gypsum 15 mm
flexible foam Parkolag
wood parquet 14 mm

B

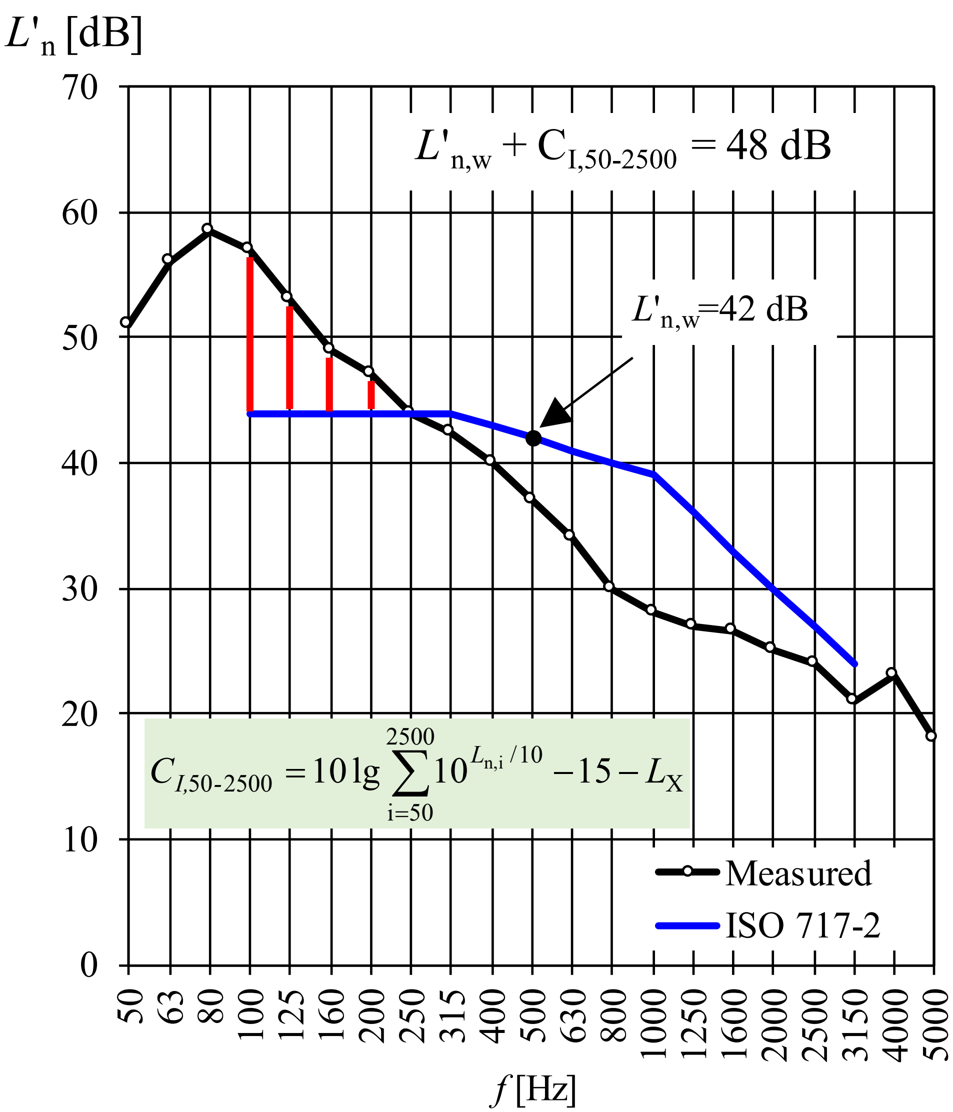
steel reinforced concrete 300 mm
flexible foam Parkolag
wood parquet 14 mm

RIL 243-1-2007

A

Frequency [Hz]	Measured [dB]	ISO 717-2 [dB]	Unfavorable deviation [dB]	$10^{L_{n,i}/10}$
50	51.0			125893
63	56.0			398107
80	58.5			707946
100	57.0	44	13.0	501187
125	53.0	44	9.0	199526
160	49.0	44	5.0	79433
200	47.0	44	3.0	50119
250	44.0	44	0.0	25119
315	42.5	44	0.0	17783
400	40.0	43	0.0	10000
500	37.0	**42**	0.0	5012
630	34.0	41	0.0	2512
800	30.0	40	0.0	1000
1000	28.0	39	0.0	631
1250	27.0	36	0.0	501
1600	26.5	33	0.0	447
2000	25.0	30	0.0	316
2500	24.0	27	0.0	251
3150	21.0	24	0.0	
4000	23.0			
5000	18.0			
SUM			30.0	2125782

$L_{n,w}$	**42**
$C_{I,50\text{-}2500}$	**6**

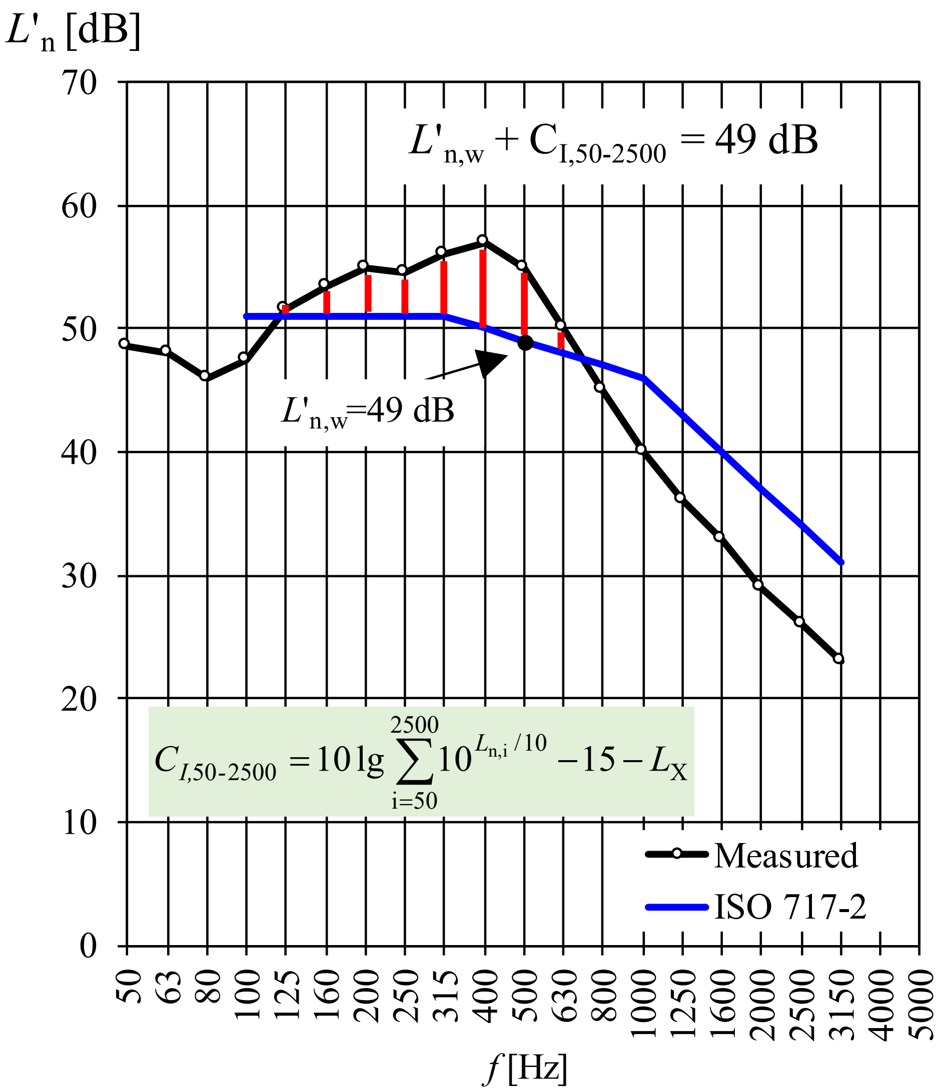


$$C_{I,50\text{-}2500} = 10\lg\sum_{i=50}^{2500}10^{L_{n,i}/10} - 15 - L_X$$

B

Frequency [Hz]	Measured [dB]	ISO 717-2 [dB]	Unfavorable deviation [dB]	$10^{Ln,i/10}$
50	48.5			70795
63	48.0			63096
80	46.0			39811
100	47.5	51	0.0	56234
125	51.5	51	0.5	141254
160	53.5	51	2.5	223872
200	55.0	51	4.0	316228
250	54.5	51	3.5	281838
315	56.0	51	5.0	398107
400	57.0	50	7.0	501187
500	55.0	**49**	6.0	316228
630	50.0	48	2.0	100000
800	45.0	47	0.0	31623
1000	40.0	46	0.0	10000
1250	36.0	43	0.0	3981
1600	33.0	40	0.0	1995
2000	29.0	37	0.0	794
2500	26.0	34	0.0	398
3150	23.0	31	0.0	
4000				
5000				
SUM			30.5	2557441

$\boldsymbol{L_{n,w}}$	**49**
$\boldsymbol{C_{I,50\text{-}2500}}$	**0**

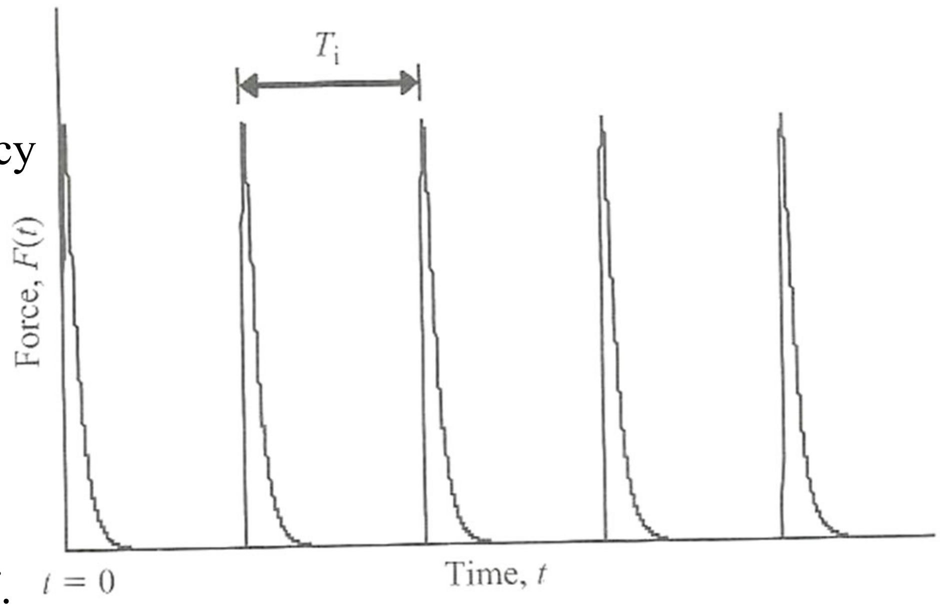


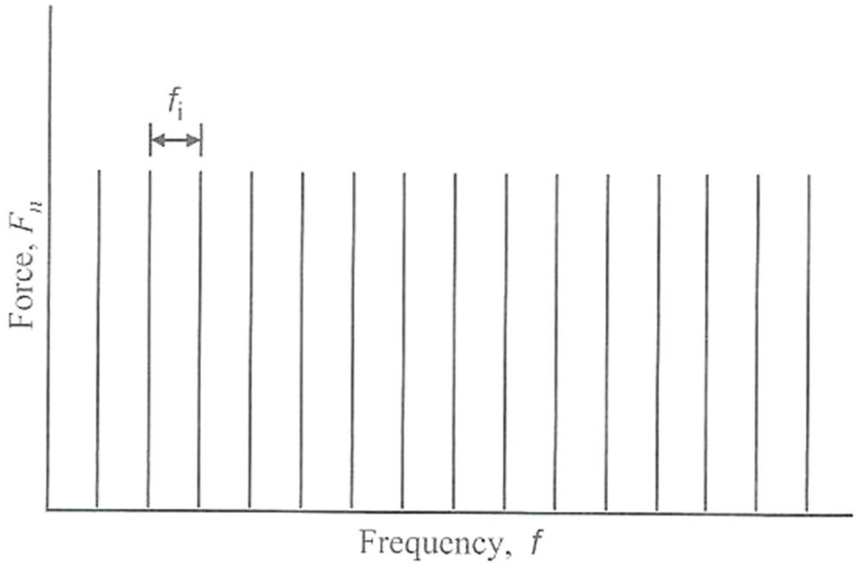
$$C_{I,50\text{-}2500} = 10\lg \sum_{i=50}^{2500} 10^{L_{n,i}/10} - 15 - L_X$$

ISO 717-2

Tapping machine

- Force is assumed consist of impacts that occur with frequency $f_i = 10$ Hz and time period $T_i = 0.1$ s from drop height of hammer (h=0.04 m, m_h=0.5 kg).
- Kinetic energy equals potential energy: $$\frac{m_h v^2}{2} = m_h g h$$
- Velocity at the impact, v_0, becomes $$v_0 = \sqrt{2gh} = 0.886\,\frac{\text{m}}{\text{s}}$$
- The magnitude of the peak force of one drop can be derived to be $$|F_n| = \frac{2}{T_i} m_h v_0 = 2 f_i m_h \sqrt{2gh}$$
- The force spectrum becomes a line spectrum with division f_i.
- For a frequency bandwidth Δf [Hz], $\Delta f / f_i$ lines exists
- Mean square force within the frequency band is $$F_{rms}^2 = \frac{|F_n|^2 \Delta f}{2 f_i} = 3.9 \Delta f$$
  - $\Delta f = 0.23 \cdot f_m$ for 1/3-octave band of middle frequency f_m
  - $\Delta f = 0.707 \cdot f_m$ for 1/1-octave band of middle frequency f_m
- The force is constant per each Δf up to appr.
  - 200 Hz: lightweight floors
  - 3000 Hz: heavyweight load-bearing floors





L_n of heavy-weight floors

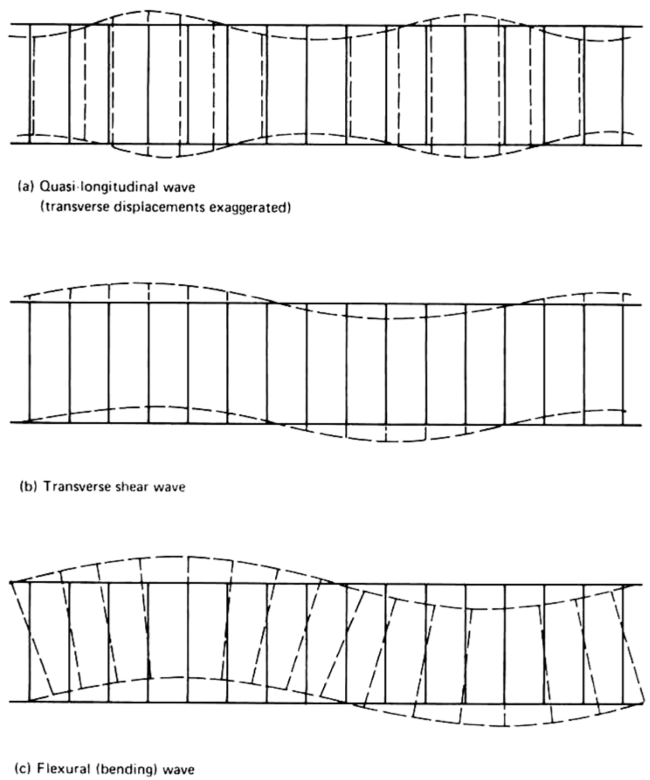
- The normalized SPL caused by tapping machine (assumed to be a point source) on a homogeneous heavy floor (e.g. concrete) can be predicted in two frequency ranges by two approximative equations.
  - m' [kg/m^2] is the surface mass of the floor
  - η is the total loss factor of the construction (frequency dependent)
  - f_c [Hz] is the critical frequency of the material
  - f_s [Hz] is the frequency where the speed of shear and bending waves are equal (see ”4 Airborne sound insulation”)
  - B [N/m] is the bending stiffness per unit width
  - c_s [m/s] is the speed of shear waves
- The values concern third-octave bands.

$$f_c = \frac{c_0^2}{2\pi}\sqrt{\frac{12(1-\mu^2)m'}{Eh^3}}$$

$$f_s = \frac{c_s^2}{2\pi}\sqrt{\frac{m'}{B}}$$

$$B = \frac{Eh^3}{12(1-\mu^2)}$$

$$c_s = \sqrt{\frac{Gh}{m'}} = \sqrt{\frac{E}{\rho_p 2(1+\mu)}}$$



$$L_n \cong 82 - 10\log_{10}\left(m'^2 \frac{\eta}{f_c}\right), \qquad f_c < f < \tfrac{1}{2} f_s$$

$$L_n \cong 82 - 10\log_{10}\left(m'^2 \frac{\eta}{f_c}\right) + 10\log_{10}\left(\frac{2f}{f_s}\right), \qquad f > \tfrac{1}{2} f_s$$

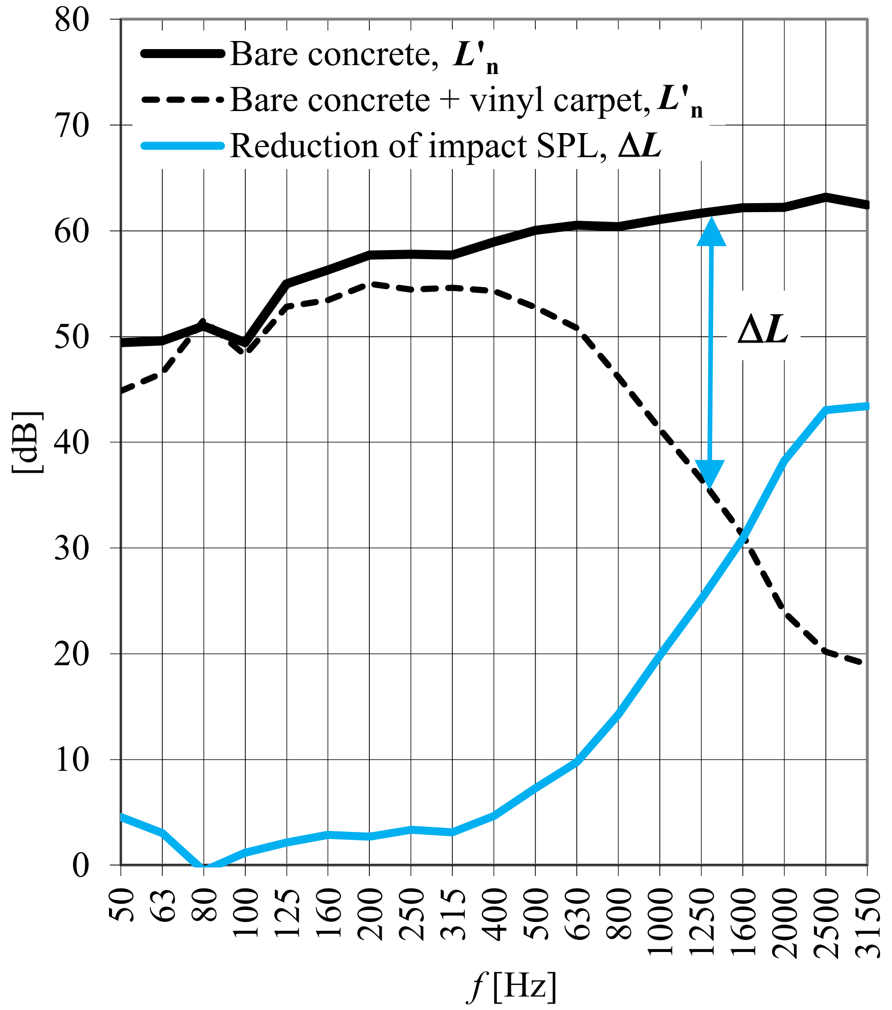
Rindel (2006) DTU

Reduction of impact SPL, ΔL and ΔL_w

- Reduction of impact SPL, ΔL, is determined in laboratory conditions according to ISO 10140-3 [dB]:

$$\Delta L = L_{n,0} - L_n$$

  - $L_{n,0}$ [dB] is the impact SPL of standard floor without floor covering
  - L_n [dB] is the impact SPL of covered floor
- Standard concrete floors:
  - steel-reinforced concrete: 140 ± 20 mm
  - wooden floor: three options C1-C3
- Impact SPL reduces with the surface mass of the concrete floor but the ΔL curve of a floor covering (or a floating floor) is applicable to any thickness.
- Performance of floor coverings or floating floors is usually reported by a single-number quantity ΔL_w. It is determined from the weighted normalized impact sound pressure levels by $\mathbf{\Delta L_w} = L_{n,w,0} - L_{n,w}$



ISO 10140-3-2010

ΔL of light floor coverings

- Flexible covering reduces the force of the tapping machine towards the floor.
- Hammer's mass, flexibility of the covering and the mass of the floor under the covering cause a mass-spring-mass system.
- The resonance frequency f_0 is:

$$f_0 = \frac{1}{2\pi}\sqrt{\frac{S_h E_t}{m_h h_t}}$$

  - S_h [m^2] is the area of the hammer
  - E_t [Pa] is the Young's modulus of the covering
  - m_h [kg] is the mass of the hammer
  - h_t [m] is the thickness of covering
- For standardized tapping machine:
  - $m_h = 0.500$ kg
  - $S_h = 700$ mm^2

- **Note: the actual resonance frequency in the dwelling depends on the stimulus' mass and area**
  - heavy impact (large force) causes lower resonances than light impact
- Floor covering does not influence the impact SPL below the resonance frequency ($f<f_0$).
- Theoretical ΔL obtained by a flexible floor covering is

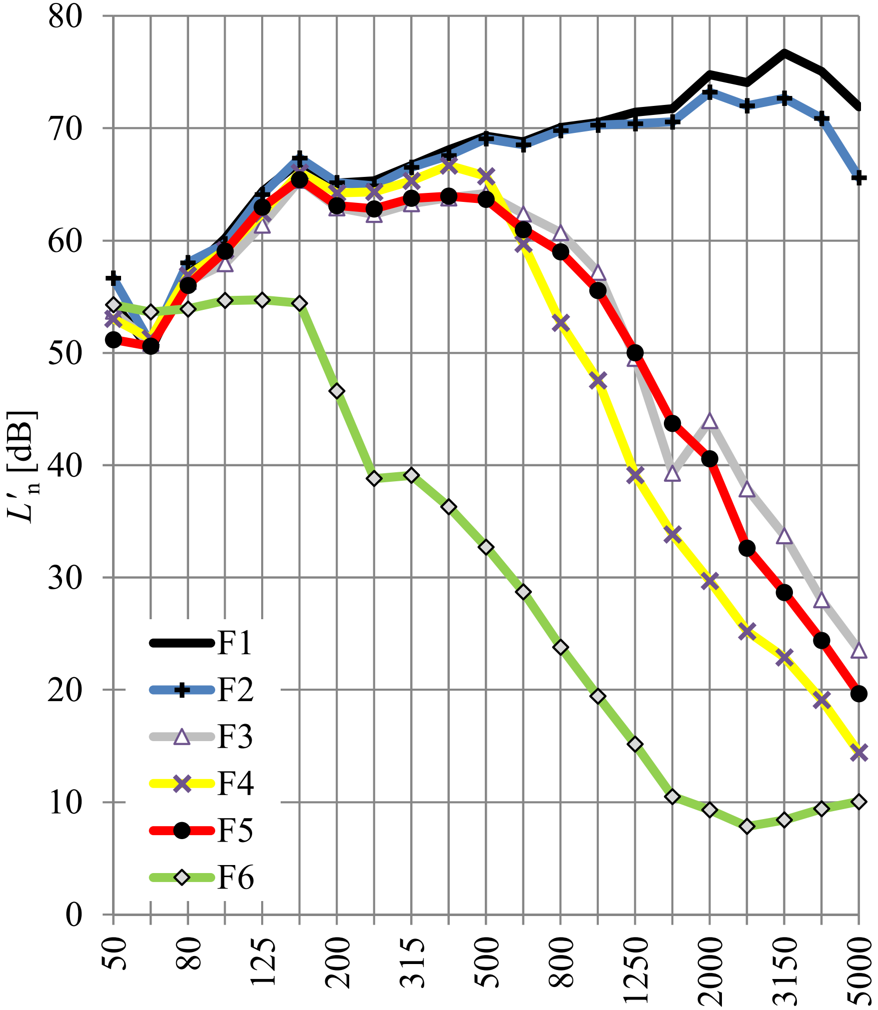
$$\Delta L \cong \begin{cases} 0, & f < f_0 \\ 40\lg\dfrac{f}{f_0} & f > f_0 \end{cases}$$

Rindel (2006) DTU

Measurement methods of Δ*L*

1. **ISO 10140-3** using 10-12 m^2 specimen
   - all types
   - steel-reinforced concrete 120-160 mm is used
2. **ISO 16251-1** using 800x1200 mm specimen
   - results with light coverings agree very well with ISO 10140-3 within 100-3150 Hz
   - results with floating floors do not necessarily agree with ISO 10140-3 below 100 Hz since the uncertainties are large for both methods due to the lack of diffuse field and due to the sample inequalities: bending of the floating floor during drying process cannot be perfectly controlled

ΔL and ΔL_w values



Data: Kylliäinen et al. (2015, 2017)
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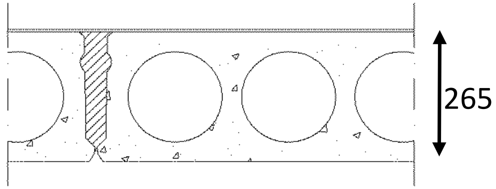
f [Hz]

F1

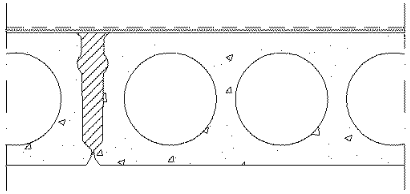
Bare floor

Hollow concrete slab 265 mm



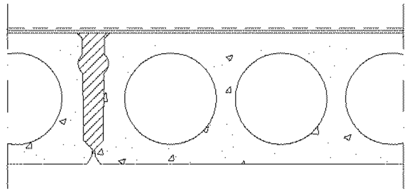
F2

F1 + hard vinyl carpet for public spaces *Estrad* (s'=3400 MN/m³), ΔL_w=2 dB



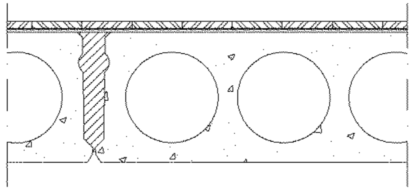
F3

F1 + soft vinyl carpet for domestic spaces *Upostep* (s'=2800 MN/m³), ΔL_w=21 dB



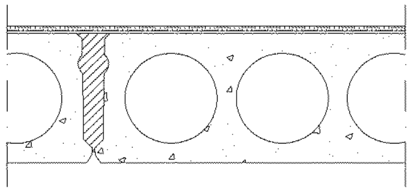
F4

F1 + soft underlayment *Tuplex* (s'=68 MN/m³) + birch parquet, ΔL_w=20 dB



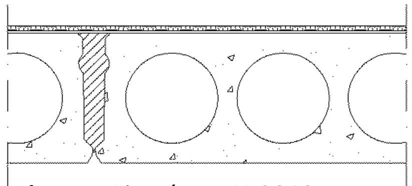
F5

F1 + hard textile carpet for public spaces *Epoca Compact* (s'=226 MN/m³), ΔL_w=21 dB



F6

F1 + soft textile carpet for domestic spaces *Milliken* (s'=80 MN/m³), ΔL_w=29 dB



Figures: Lietzén, TTY, 2012

A case study in a row house

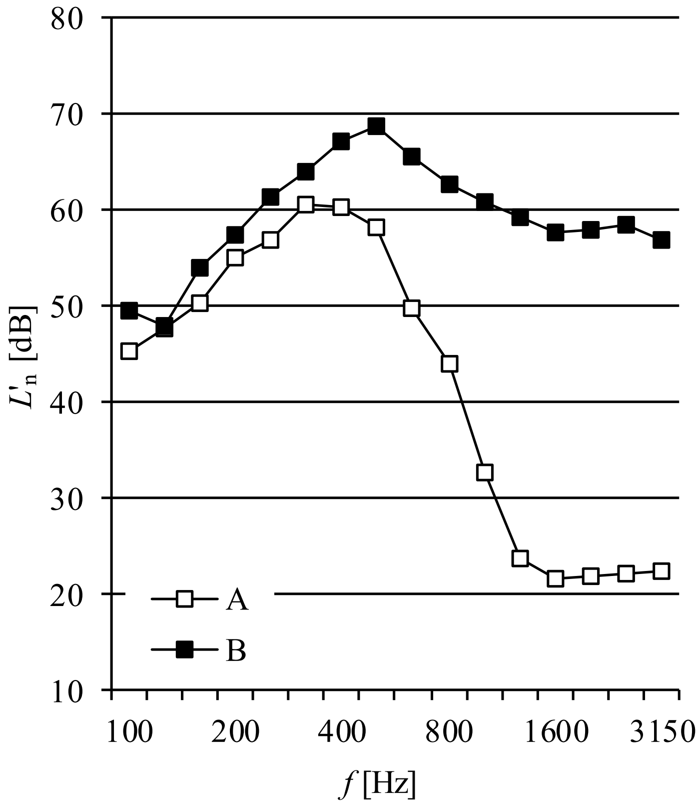
Improvement of horizontal impact SPL

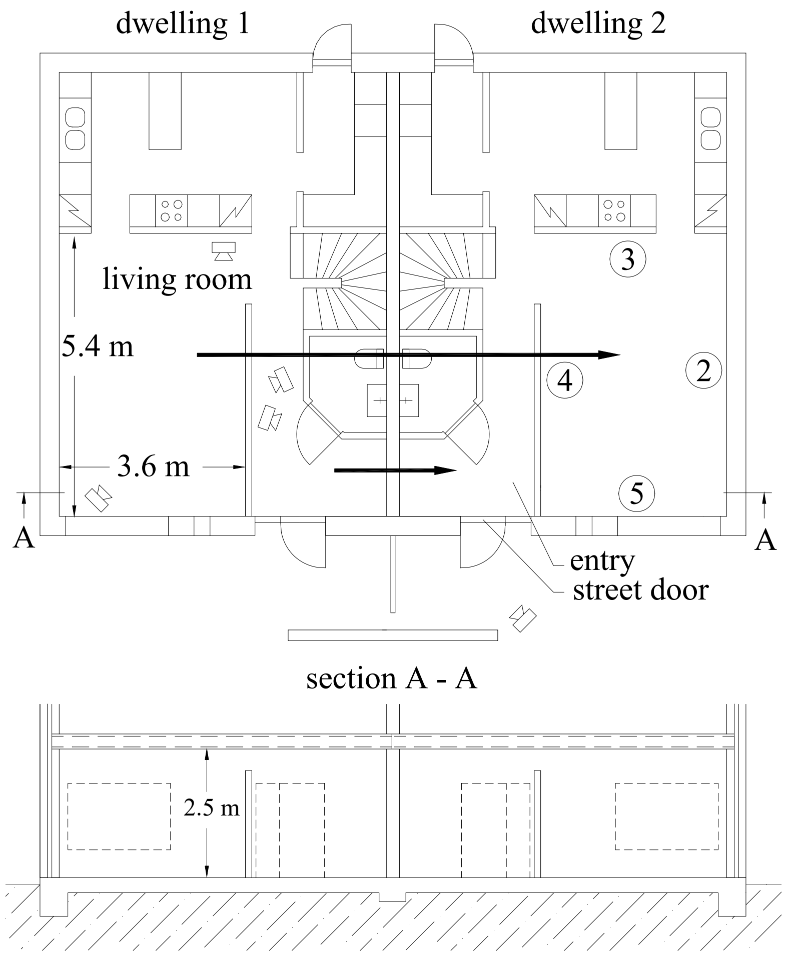
Hongisto (2001) Appl Acoust

Common floor, steel reinforced concrete 160 mm, no construction joint

A: Tuplex + parquet (living room) $L'_{n,w}$=51 dB

B: Tiles directly casted to the concrete (kitchen) $L'_{n,w}$=65 dB





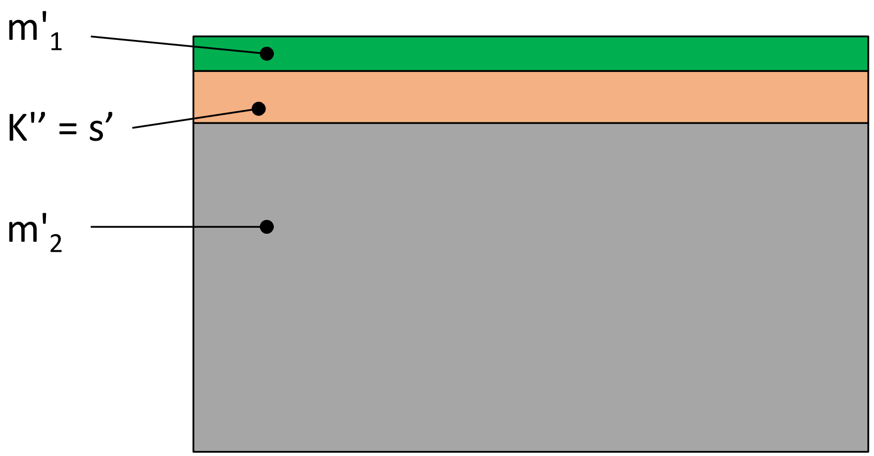
Floating floor – resonance frequency

- Floating floor is a construction where a floating slab m'$_1$ and the load bearing slab m'$_2$ are separated by a resilient layer having dynamic stiffness per unit area of s'
- Resonance frequency f_0 [Hz] is determined by:

$$f_0 = \frac{1}{2\pi}\sqrt{K''\frac{m'_1+m'_2}{m'_1\,m'_2}}$$

  - m'_1 [kg/m^2] surface mass of the floating layer
  - K'' [**N**/m^3] dynamic stiffness per unit area of the flexible layer
  - m'_2 [kg/m^2] surface mass of the load-bearing floor
- The manufacturers declare the properties of the flexible layer by ***s'*** [**MN**/m^3] so that the calculation of f_0 is done according to

$$f_0 = 159\sqrt{\frac{s'}{m'_1}}$$



$$f_0 = \frac{1}{2\pi}\sqrt{K''\frac{m'_1+m'_2}{m'_1\,m'_2}} \xrightarrow{m'_2 >> m'_1} \frac{1}{2\pi}\sqrt{K''\frac{1}{m'_1}}$$

$$159 = \frac{1}{2\pi}\sqrt{1.000.000}$$

Floating floor examples

Heavy floating floor

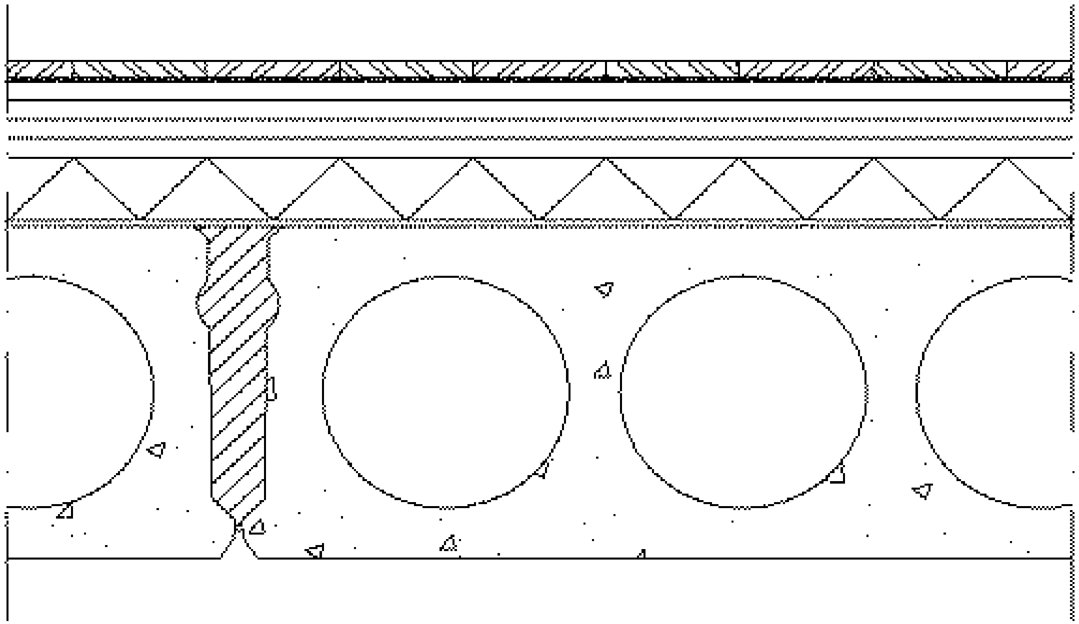
- A ”real” floating floor refers usually constructions with a low mass-air-mass resonance frequency, f_0<150 Hz.

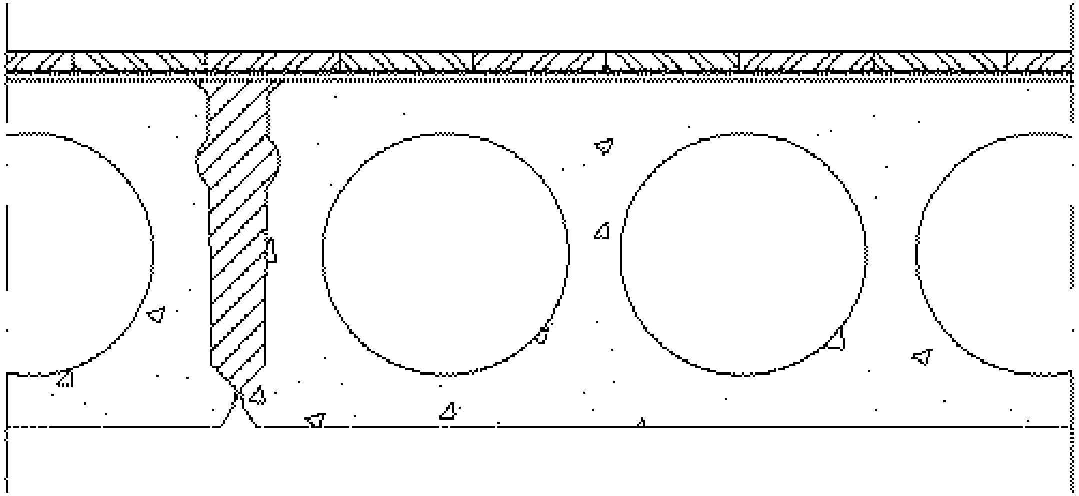
Light floating floor

- Parquet with soft underlayment is also floating floor although it is considered as a floor covering (topping).
- Resonance frequency is high, f_0 >400 Hz.
- If a light floating floors is installed on a heavy floating floor, two resonance frequencies are obtained. The higher is usually inaudible

The benefit (ΔL) of floating floor:

- Below ½f_0: nothing.
- ½f_0:-1½f_0: disadvantage by 0… 15 dB
- Within f_0 and f_d: -12 dB/octave
- Above f_d: -6 dB/octave





Calculation of ΔL

Schiavi (2018, Appl Acoust)

Floating slab is globally reacting i.e. resonating:

- The floating slab radiates sound efficiently on the entire area and interacts with the resilient material in the whole floor area although the stimulus is on one point.
- Slab is resonant, when $f > f_c$, where f_c is the critical coincidence frequency of the floating slab.
- Cement-based floating slabs usually have $f_c < 300$ Hz and thus they are resonant in a large frequency range.

$$\Delta L = -15 \cdot \log_{10}\left(\sqrt{\frac{1+\eta_m\left(\frac{f}{f_0}\right)^2}{\eta_m\left(\frac{f}{f_0}\right)^2+\left[1-\left(\frac{f}{f_0}\right)^2\right]^2}}\right)$$

Floating slab is locally reacting i.e. non-resonant

- Floating slab interacts with the elastic material only locally close to the stimulus point (within half bending wavelenght). Outside this area acoustic short-cirquit prevents efficient radiation of sound.
- Slab is non-resonant, when $f < f_c$. Building boards usually have $f_c > 1000…3000$ Hz where they behave as non-resonant slabs.
- η_m is the loss factor of resilient layer. Typical values 0.05-0.30.

$$\Delta L = -20 \cdot \log_{10}\left(\sqrt{\frac{1+\eta_m\left(\frac{f}{f_0}\right)^2}{\eta_m\left(\frac{f}{f_0}\right)^2+\left[1-\left(\frac{f}{f_0}\right)^2\right]^2}}\right)$$

Determination of *K*”

- Specimen size 20x20 cm
- Thickness *d* [m] according to the product
- Load plate 8 kg over the specimen
- Load plate is shakened and the system’s resonance frequency f_r [Hz] is determined with FFT analysis
- Dynamic stiffness per unit area K'' [N/m³] is

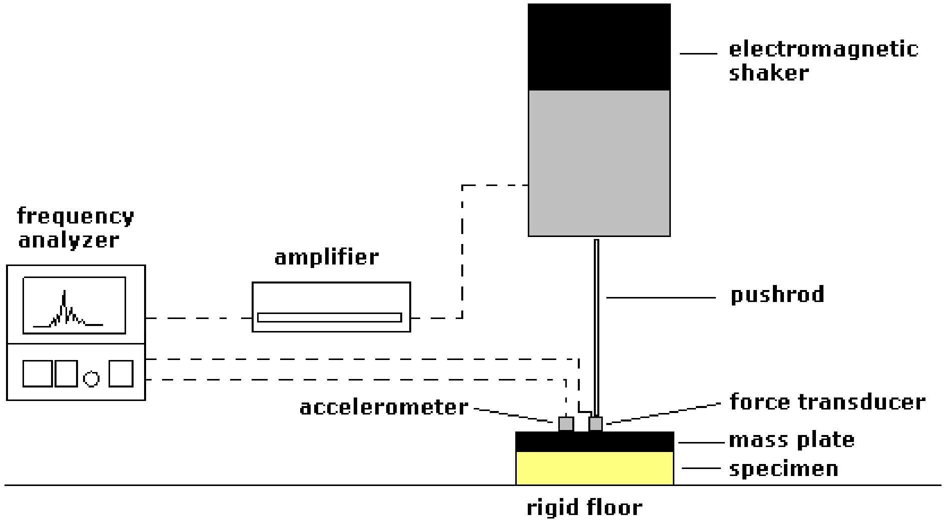
$$K'' = \frac{4\pi^2 m_t f_r^2}{A}$$

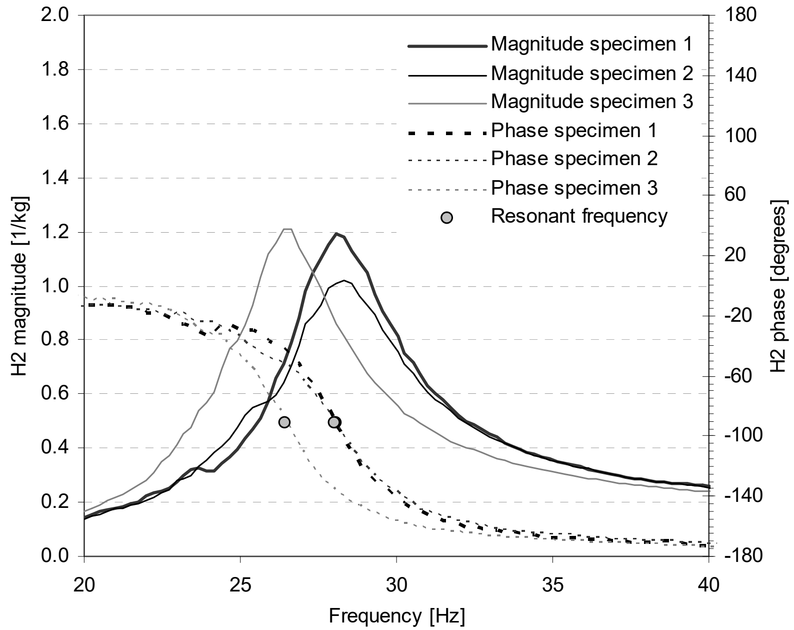
  - m_t = 8 kg.
  - A = 0.04 m²
- Final reported *K*” depends on the properties of both the skeletal frame determined above, K_f” and air within the pores, K_a”:

$$K'' = K_f'' + K_a''$$

$$K_a'' = \frac{p_0}{d\left(1 - \frac{\rho_m}{\rho_f}\right)}$$

  - p_0=101300 Pa
  - ρ_m [kg/m³] is the density of material
  - ρ_f [kg/m³] is the density of skeletal frame
- K_a” is meaningful if r<100 kPa/m² in lateral direction





Examples of *s*’ values for some materials

Product	Thickness [mm]	Density [kg/m3]	s' [MN/m3]
Isover RKL-31 wool	50	45	3
Isover FLO-50 wool	50	92	12
EPS - weber.floor 4900 Comfort grooved board 50 mm	50		12
EPS - weber.floor 4900 Comfort grooved board 35 mm	35		13
Isover VKL-13 wool	13	115	16
EPS - weber.floor Comfort Lite 30 mm	30		16
Tuplex felt used under parquet	2.1	77	68
Textile floor Milliken (soft, residential rooms)	8.2	470	80
Textile floor Epoca Compact (hard, public rooms)	3.8	550	230
Vinyl floor Upostep (soft, residential rooms)	2.4	703	2900
Vinyl floor Estrad (hard, public spaces)	2.2	1420	3400

5.1

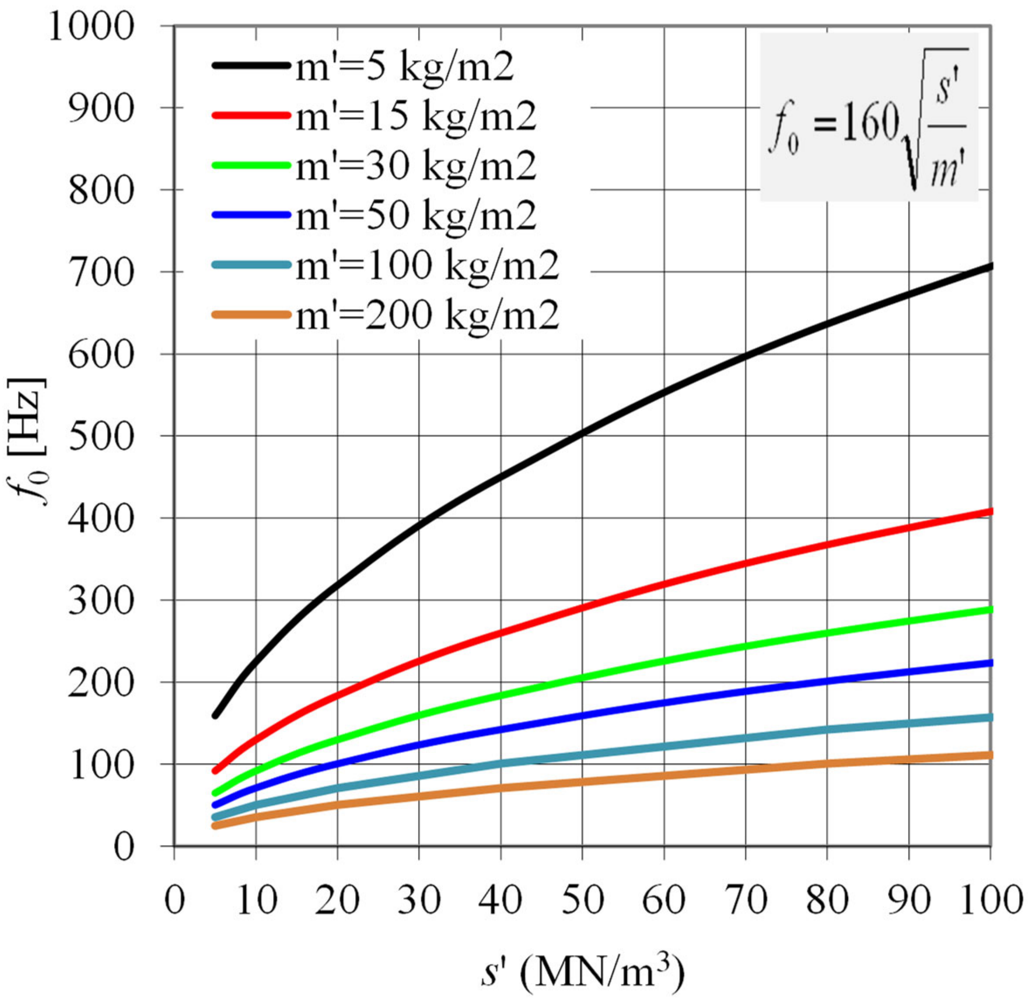
Dynamic stiffness per unit area of a flexible wool is 10 MN/m3.
Calculate the resonance frequency, if the wool is installed on top of concrete floor (450 kg/m2) and the following floating floor is installed on top of it:

a) 22 mm chipboard
b) two layers of 22 mm chipboard
c) 60 mm cast concrete

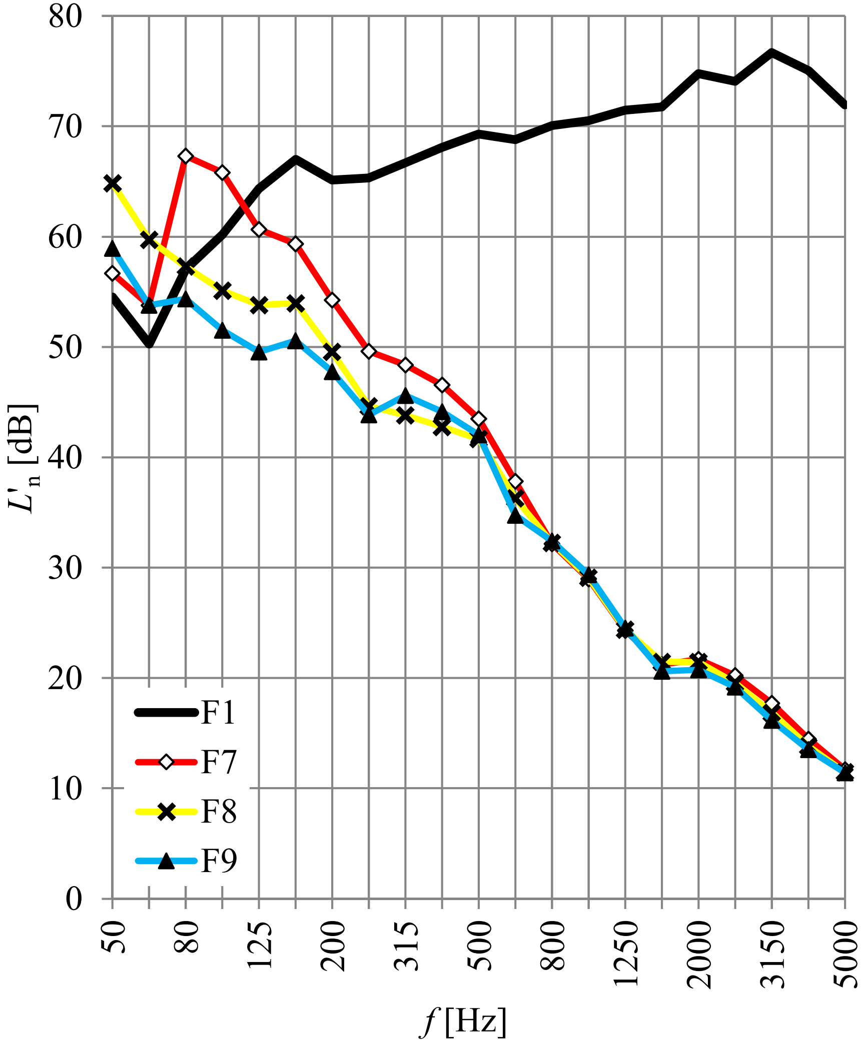
$$f_0 = 159\sqrt{\frac{s'}{m'_1}}$$

Floating floors – typical range of resonance frequencies

- f_0 reduces with increasing mass of the panel and reducing stiffness of flexible layer
- Ranges of material properties:
  - 22 mm chipboard 15 kg/m^2
  - Cast concrete 80 mm, 200 kg/m^2
  - Tuplex s'=68 MN/m^3
  - 50 mm wool for floors, s'=11 MN/m^3



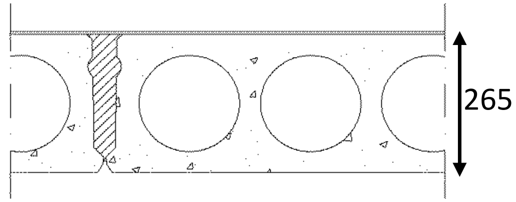
Floating floors - ΔL



Kylliäinen et al. (2017) **Acta Acust Acust**

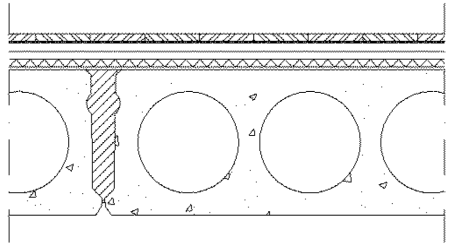
F1

Hollow concrete slab 265 mm
No covering



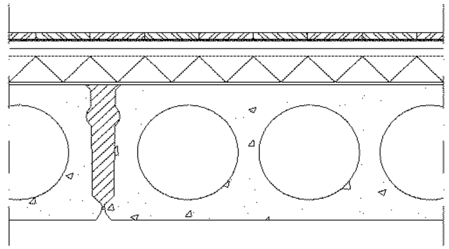
F7 - f_0=80 Hz

F1
wool 13mm (s'=16.1 MN/m³)
gypsum 2x15 mm (30.8 kg/m²)
Tuplex + parquet 14 mm



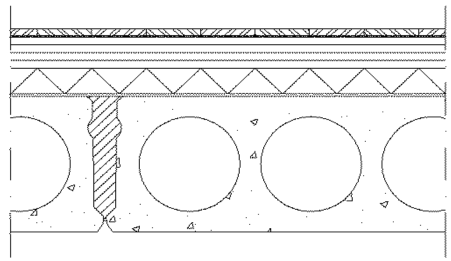
F8 - f_0=50 Hz

F1
wool 50 mm (s'=11.5MN/m³)
gypsum 2x15 mm (30.8 kg/m²)
Tuplex + parquet 14 mm



F9 - f_0=31 Hz

F1
wool 50 mm (s'=11.5MN/m³)
gypsum 4x15 mm (61.6 kg/m²)
Tuplex + parquet 14 mm



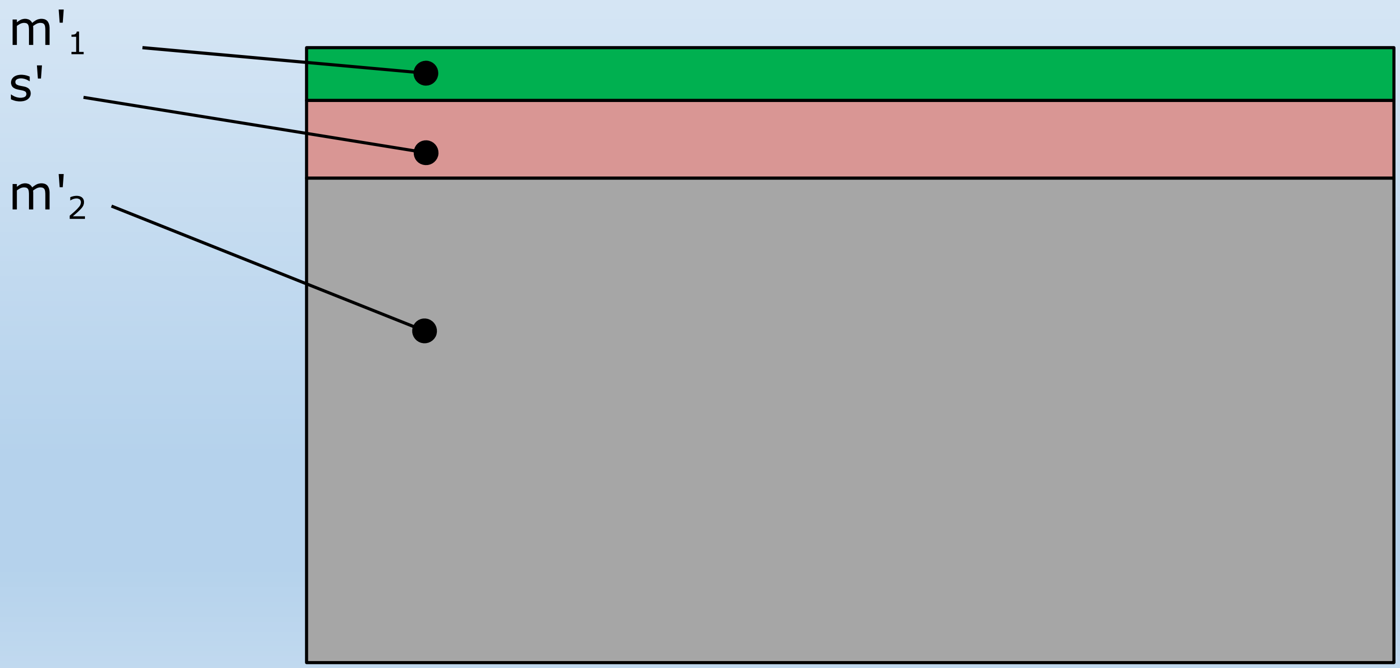
5.2

Floating floor consists of 265 mm hollow concrete slab, 20 mm flexible layer (s'=20 MPa/m3) and and cast concrete 60 mm (r=1700 kg/m3).

The flexible material is homogeneous and it can be produced at any thickness.

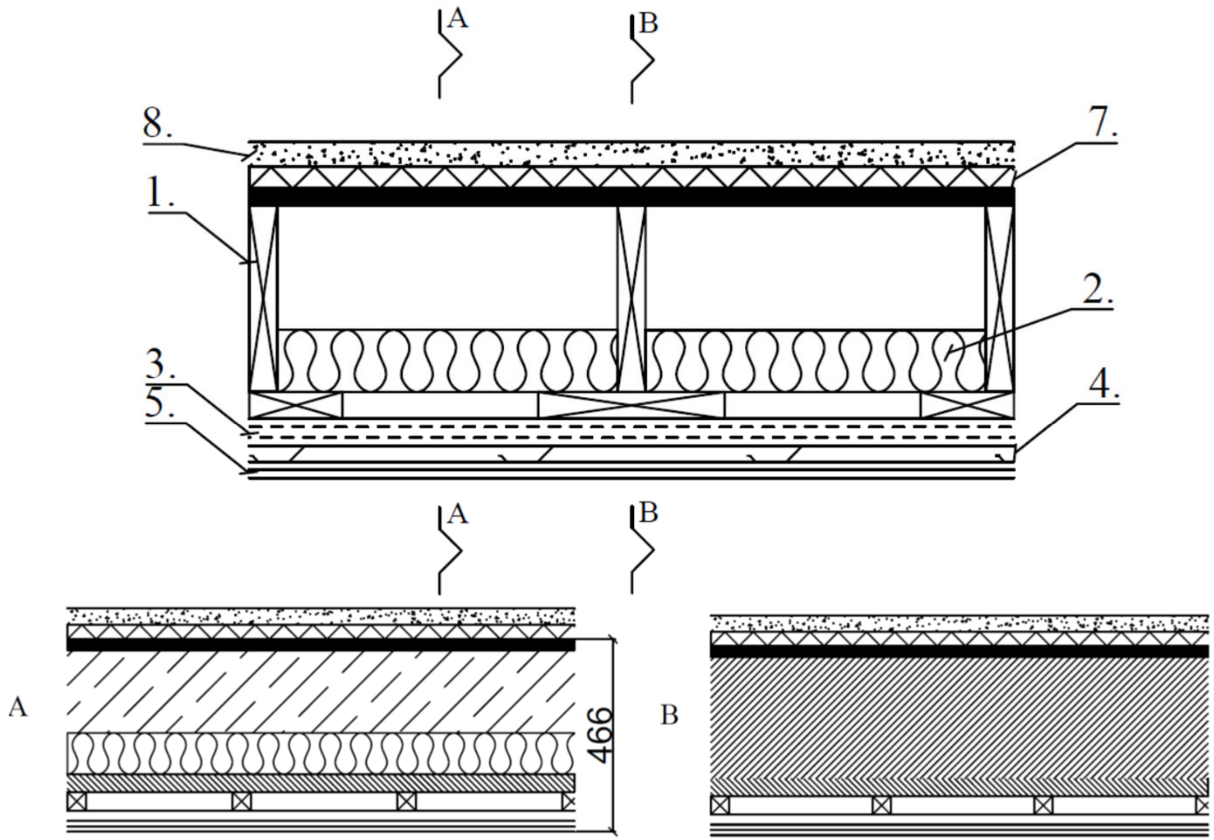
What should be the thickness to achieve f0=50 Hz?

$$f_0 = 159\sqrt{\frac{s'}{m'_1}}$$



Timber floors

- Timber is increasingly favored in apartment buildings
- Typical timber load-bearing slabs
  - Rib slab
  - Hollow box slab
  - CLT slab
  - LVL slab
- Timber density is 600 kg/m^3 and concrete density is 2200 kg/m^3: the achievement of regulated ISPL with timber slabs requires usually more than additional layer, which is resiliently mounted to the slab
  - Resilient ceiling (see figure 4+5)
  - Floating floor (see figure 7+8)
  - Installation floor (not in the figure)

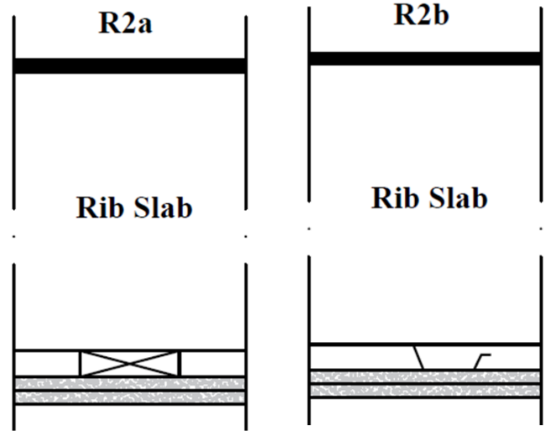


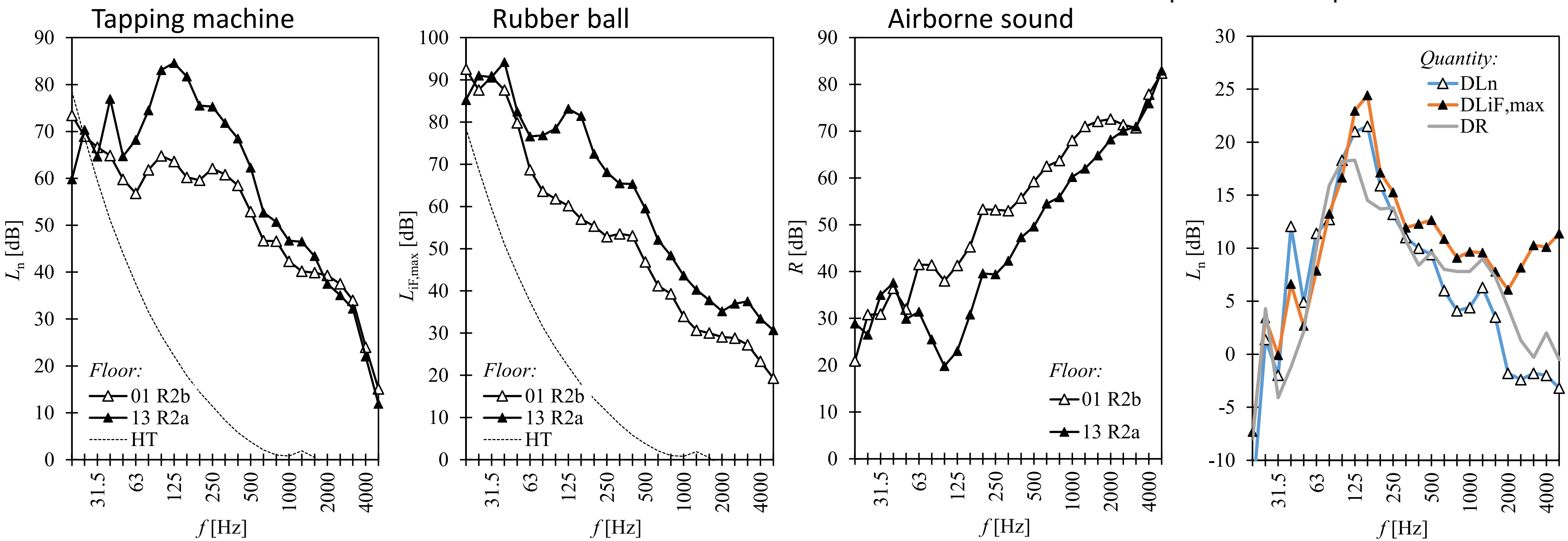
1. Ribslab 370mm
2. 100 mm wool 10 kg/m3
3. 45 mm timber stud 45x45 mm cc 600 mm
4. 25 mm resilient stud xxx MN/m2 cc 400 mm
5. 13 mm gypsum board 8.4 kg/m2 (screwing cc 200 mm ends cc 300 mm sides)
6. 13 mm gypsum board 8.4 kg/m2 (screwing cc 200 mm ends cc 300 mm sides)
7. 35 mm EPS 12 MN/m3
8. 40 mm screed 70 kg/m2

Timber box slab: Effect of resilient ceiling

- Laminate + soft underlayment
- Box slab with wool
- Stud (**resilient b vs. rigid a**)
- 2 gypsum boards

		01 R2b	01 R2b	Change
	Ln,w	55	72	17
	Ln,w+CI	55	74	19
	Ln,w+CI,50-2500	56	74	18
	LiA,Fmax	56	73	17
	Rw	62	49	-13

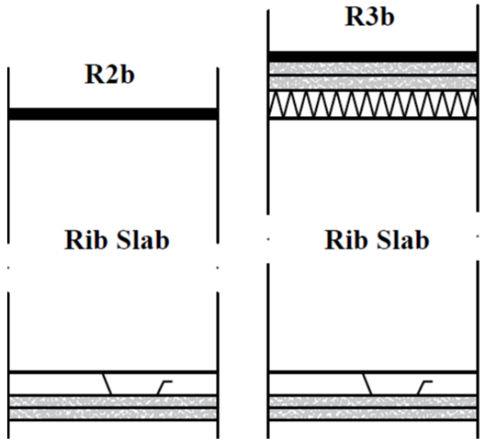




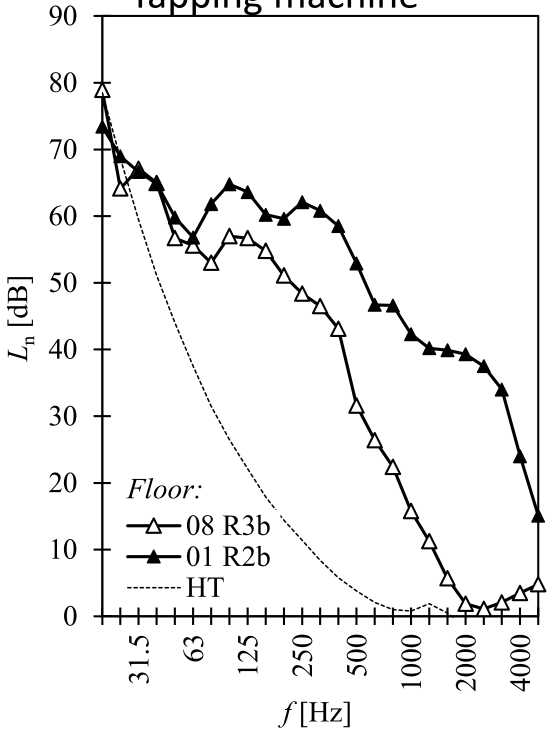
Timber box slab: Effect of floating floor

- Laminate + soft underlayment
- **Floating floor R3b (13 mm wool + 2 x 15 kg/m^2)**
- Box slab with wool
- Resilient stud
- 2 gypsum boards

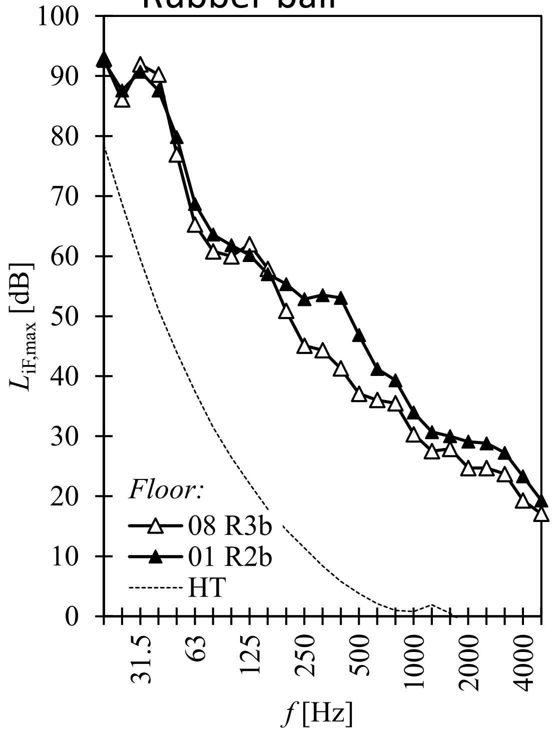
		08 R3b	08 R3b	Change
	Ln,w	46	55	9
	Ln,w+CI	47	55	8
	Ln,w+CI,50-2500	49	56	7
	LiA,Fmax	52	56	4
	Rw	70	62	-8



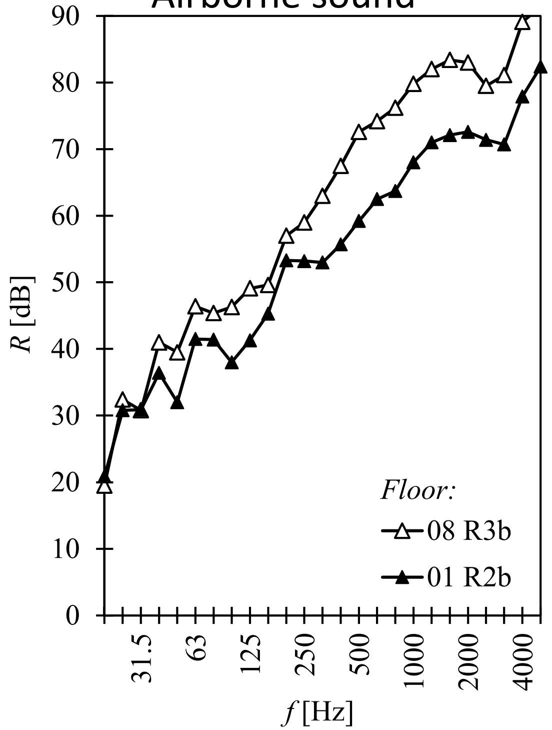
Tapping machine

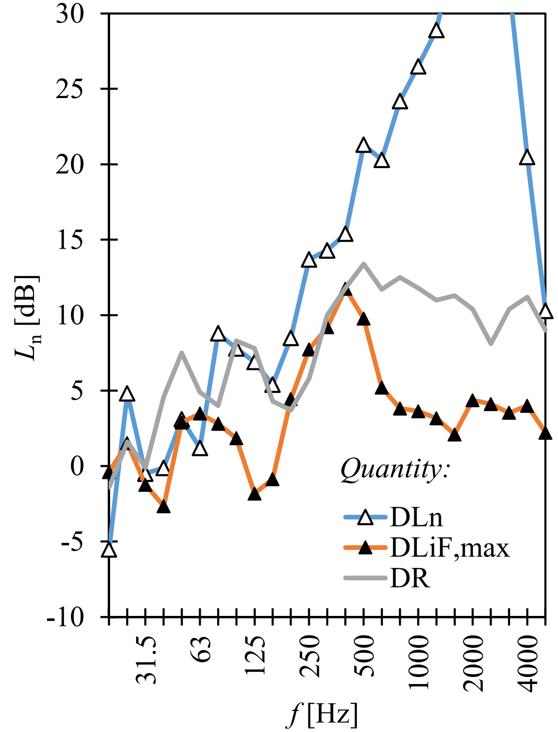


Rubber ball



Airborne sound





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