POLITECNICO DI MILANO

# Acoustics in Buildings:

## Building Acoustics

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## Two targets



Acoustics in Building

has two targets

Architectural Acoustics

- **Acoustical Quality**
  - **Quality of the sound in closed space (also sound insulation, but mainly sound absorption, first reflection utilization to reinforce the sound, etc.)**

    ➔ *Sound Correction*

  **Room Acoustics**

- **Acoustical Comfort**
  - **Reduction of Sound Pollution ➔ Noise**
  - **Sound Insulation (Soundproofing)**

    ➔ *Noise Reduction*

  **Building Acoustics**

## The noise disturbance according to the Law: Building acoustic requirements D.P.C.M 5-12-1997



| Building Category | $R'_w$ | $D_{2m,n,T,W}$ | $L'_{n,w}$ | $L_{ASmax}$ | $L_{Aeq}$ |
|---|---|---|---|---|---|
| D | 55 | 45 | 58 | 35 | 25 |
| A,C | 50 | 40 | 63 | 35 | 35 |
| E | 50 | 48 | 58 | 35 | 25 |
| B,F,G | 50 | 42 | 55 | 35 | 35 |

$R'_w$ Weighted Apparent Sound Reduction Index, in dB(A)

$D_{2m,n,T,w}$ Facade Weighted Standardized Level Difference Index, in dB(A)

$L'_{n,w}$ Weighted Normalized Impact Sound Pressure Level Index, in dB(A)

$L_{ASmax}$ Maximum A-weighted sound pressure level with time constant slow, in dB(A)

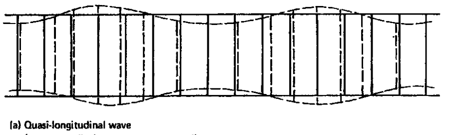
$L_{Aeq}$ Equivalent Continuous Sound Pressure Level, A-weighted, in dB(A)

- Category A: buildings used as residences or similar
- Category B: buildings used as offices and similar
- Category C: buildings used as hotels, guest houses and similar activities
- Category D: buildings used as hospitals, clinics, nursing homes and similar
- Category E: buildings used for school activities at all levels
- Category F: buildings used for recreation or worship or similar activities
- Category G: buildings used for commercial or similar purposes



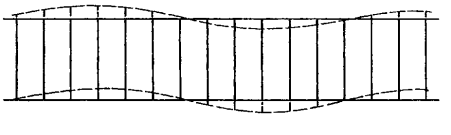
## Partitions Vibration





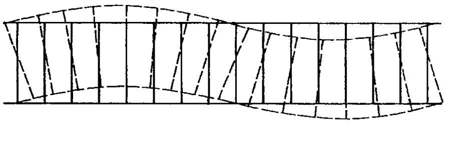
(a) Quasi-longitudinal wave (transverse displacements exaggerated)

$$c_L = \sqrt{\frac{E}{\rho\left(1-\nu^2\right)}}$$



(b) Transverse shear wave

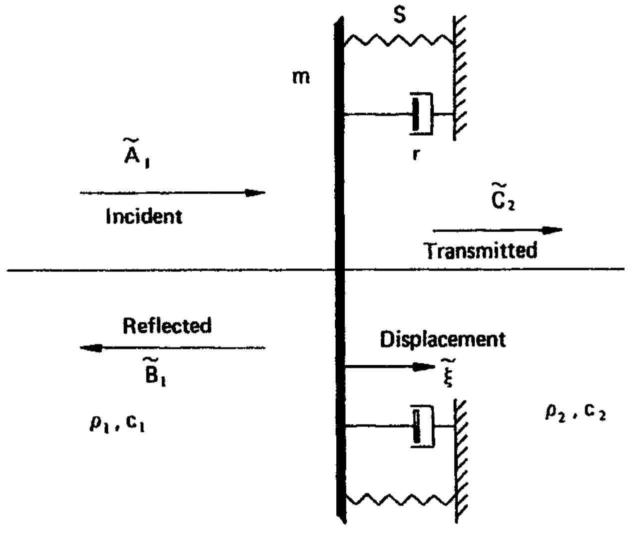
$$c_T = \sqrt{\frac{E}{2\rho(1+\nu)}}$$



(c) Flexural (bending) wave

$$c_b = \sqrt[4]{\frac{h^2 E}{12\rho\left(1-\nu^2\right)}} \cdot \sqrt{\omega}$$

## Normally Loaded Partition: Mass-Spring-Dumper 1 D.F. Model








## Transmission Loss (or Sound Reduction)

The Transmission Loss, $\boldsymbol{TL}$, or Sound Reduction, $\boldsymbol{R}$, of a partition **without any discontinuity** is defined as:

$$R = TL = 10 \cdot \log_{10}\left(\frac{\dot{W}_{inc}}{\dot{W}_{tras}}\right) = 10 \cdot \log_{10}\left(\frac{1}{\tau}\right)$$

where

$\dot{W}_{inc}$ the power of incident wave coming towards a defined partition

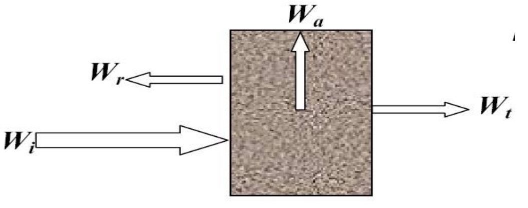
$\dot{W}_{tras}$ is the power of transmitted wave going away from the defined partition

$\tau$ is the partition transmission coefficient (or acoustics transmittance)

## Acoustic absorption



The absorption mechanisms are manifold: the sound vibration can put in motion the surface, or is the air contained in the porosity of the material to come into movement, or both phenomena may occur simultaneously. In any case, the outcome is the dissipation of sound energy into internal energy (heat).

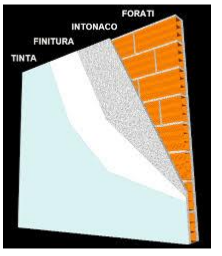


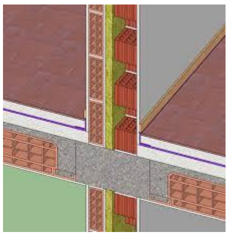

The absorbed fraction of the incident energy in the reflection from a wall is called *sound absorption coefficient* $\alpha$





# Sound Reduction Index Estimation



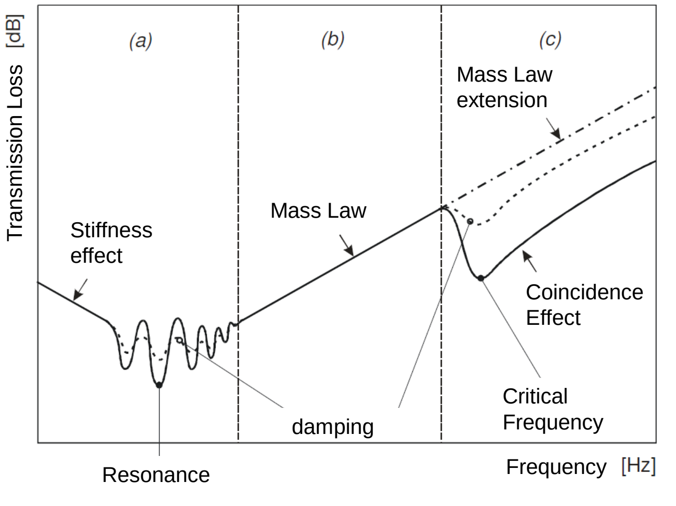





## *R* as frequency function



Sound Reduction Index of a homogenous slab as function of frequency



## Sound Reduction Index estimation: "Mass Law "

In the linearity range between $R$ and $f$ (frequency), the first can be given as function of the second as :

**normal incidence**

$$R_0 = 20 \cdot \log_{10}\left(f \cdot M_S\right) - 42{,}3 \qquad [dB]$$

**oblique incidence with incidence angle $\theta$**

$$R_\theta = 20 \cdot \log_{10}\left(f \cdot M_S \cdot \cos(\theta)\right) - 42{,}3 \qquad [dB]$$

**diffuse or quasi-diffuse sound field**

$$R_{diff} = R_0 - 10 \cdot \log_{10}\left(0{,}23 R_0\right) \qquad [dB]$$

$$R_{diff} = R_0 - 5 \qquad [dB] \qquad \text{for } R_0 > 15\ dB \text{ and } \theta_{i,\lim} = 78°$$

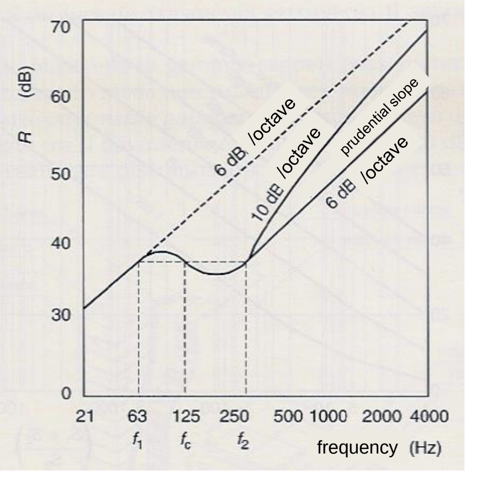




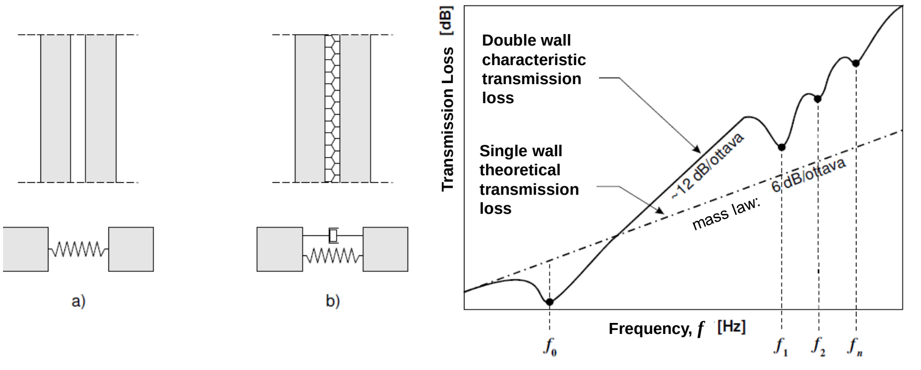
## Coincidence: estimation of *R*

- $R$ ~ constant for a range of frequencies around the critical coincidence frequency;
- known $R_c$ , $f_c$, and $f_1$-$f_2$ , a horizontal segment is traced from the straight line, which represents the law of mass, at frequency $f_1$ to frequency $f_2$;
- the continuation of the R-f relation is traced as a line segment with a slope equal to 6 dB/octave.

Conservative approach



## Double wall




Mechanical equivalent model of a double wall:

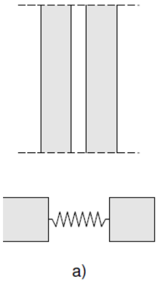
a) independent masses connected by elastic element (air gap)

b) independent masses connected by elastic element and viscous dumper (interposition of sound-absorbing material)





## Double wall with air gap




a) independent masses connected by elastic element :

**Wall with air gap**

- If the frequency is less than $f_0$ , it behaves as a homogeneous wall of mass
  $m_{eq} = m_1 + m_2$
- if the frequency is greater than $f_0$ , the slope, in the mass law validity area, is greater than that of the single wall:

12 dB/octave versus 6 dB/octave

Air gap resonance frequency:

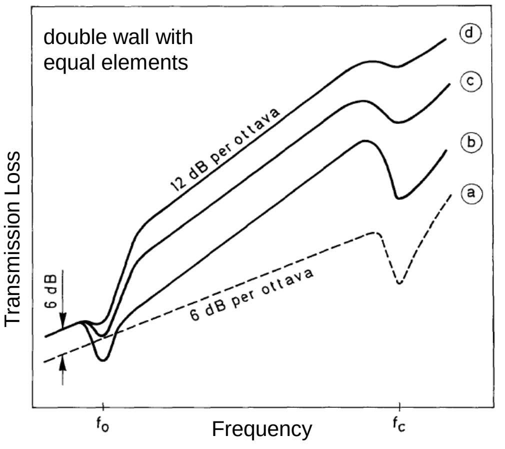
$$f_0 = 60 \cdot \sqrt{\frac{1}{d}\left(\frac{1}{m_1} + \frac{1}{m_2}\right)}$$

d = air gap thickness [m]

$m_1$, $m_2$ = areic mass of each single wall [kg/m²]

# Double wall with interspace






Performance of the sound reduction index R for diffuse incidence

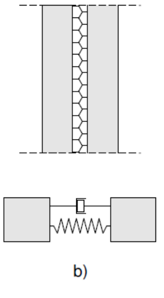
a. single wall
b. double wall with air gap
c. double wall with interspace partially filled with soundproofing material
d. double wall with interspace completely filled with soundproofing material



# Double wall with interspace



**Estimation** of sound reduction for double wall with an soundproofing material inside the cavity (case b), if MESURED VALUES of $R_1$ and $R_2$ are separately known (diffuse incidence):




$$R \cong R_1 + R_2 + 20\log_{10}(d \cdot f) - 14.4$$

for $f \le \dfrac{c}{2\pi d} = \dfrac{343}{2\pi d}$

$$R \cong R_1 + R_2 + 3$$

for $f > \dfrac{c}{2\pi d} = \dfrac{343}{2\pi d}$

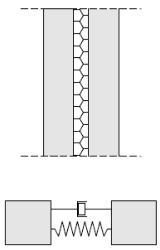
where

$d$ = interspace thickness

Experimental relation: Goesele K Prediction of the sound transmission loss of double partitions (without structure borne connections). Acustica 1980;45:218-27 .

## Double wall with interspace

**Estimation** of sund reduction for double wall with an soundproofing material inside the cavity (case b), if CALULATED VALUES of $R_1$ and $R_2$ are separately known (diffuse incidence):



b)

$$R \cong 20\log_{10}\left[(m_1 + m_2)\cdot f\right] - 47 \qquad f < \frac{2}{3} f_0$$

$$R \cong R_1 + R_2 + 20\log_{10}(d \cdot f) - 29 \qquad f_0 < f < f_1$$

$$R \cong R_1 + R_2 + 6 \qquad f > f_1$$

$$f_0 = 60 \cdot \sqrt{\frac{1}{d}\left(\frac{1}{m_1} + \frac{1}{m_2}\right)} \qquad f_1 = \frac{c}{2\,d} = \frac{343}{2\,d}$$

where

$d$ = interspace thickness

Warnock ACC, Fasold W. Sound insulation: airborne and impact. Encyclopedia of acoustics, New York: Wiley-Interscience, 1997. Vol. 3: pp. 1129-61.



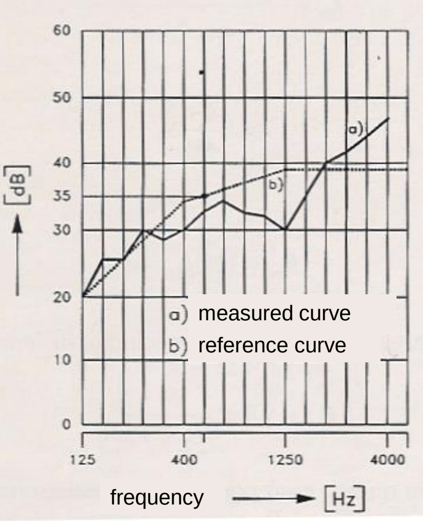


# The Weighted Indices

## Airborne Sound Insulation Indices – EN ISO 717-1

To evaluate the weighted sound reduction index of vertical walls at 500 Hz, the EN ISO 717 reference curve is shifted of 1 dB (0,1 dB for the expression of uncertainty) towards the measured curve until the sum of unfavourable deviations is as large as possible, but not more than 32,0 dB (measurement in 16 one-third-octave bands) or 10,0 dB (measurement in 5 octave bands). An unfavourable deviation at a particular frequency occurs when the result of measurements is less than the reference value. Only the unfavourable deviations shall be taken into account.

The weighted sound reduction index $\mathbf{R_w}$ (or $\mathbf{R'_w}$, or $\mathbf{D_{n,w}}$ or $\mathbf{D_{nT,w}}$) is then the value, in decibels (or 1/10 dB for the expression of uncertainty), of the reference curve at 500 Hz, after shifting it in accordance with this procedure.



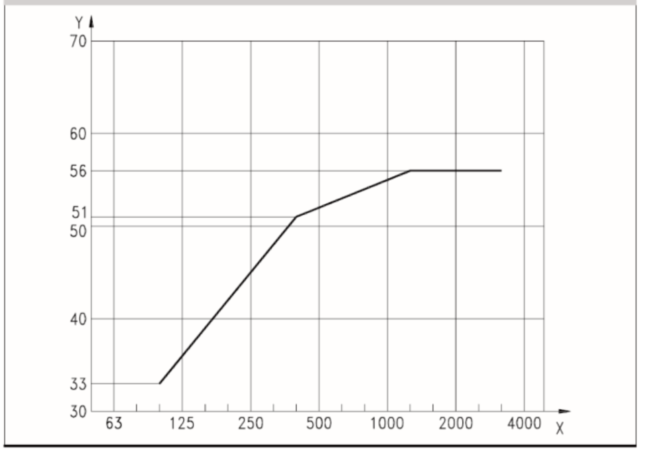





## Airborne Sound Insulation Indices – EN ISO 717-1
## $X_w$ at 500 Hz

**Curve of reference values for airborne sound, one-third-octave bands**
**Key**
**X frequency in Hz**
**Y reference value**

$$\Delta Y = \sum_i \max\left[0; Y_{ref} - Y_{meas}\right]_i < 32$$



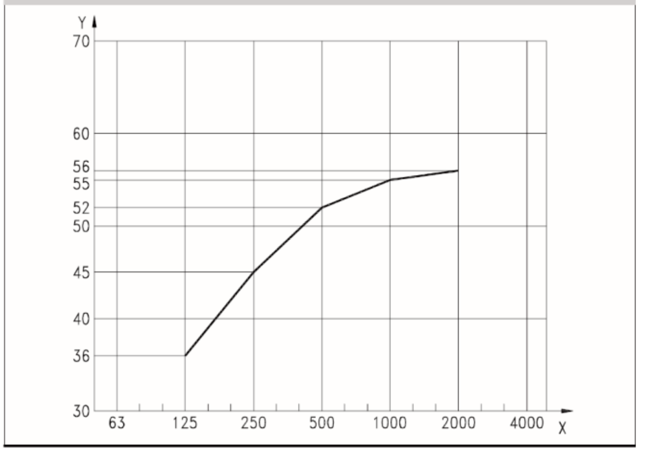

**sum of unfavourable deviations is as large as possible, but not more than 32,0 dB, measurement in one-third-octave bands**

**The same procedure applies to all of the characteristic Airborne Sound Insulation Indices**

## Airborne Sound Insulation Indices – EN ISO 717-1 $X_w$ at 500 Hz



**Curve of reference values for airborne sound, octave bands**
**Key**
**X frequency in Hz**
**Y reference value**




$$\Delta Y = \sum_i \max\left[0; Y_{ref} - Y_{meas}\right]_i < 10$$

**sum of unfavourable deviations is as large as possible, but not more than 10,0 dB, measurement in octave bands**

**The same procedure applies to all of the characteristic Airborne Sound Insulation Indexes**



## Airborne Sound Insulation Indices – EN ISO 717-1 $X_w$ at 500 Hz: spectra adaptation terms



Spectra adaptation terms, $C_j$, in decibel, shall be calculated with the specific sound spectra *j* from the following equation:

$$C_j = X_{Aj} - X_w$$

where:

j is the subscript for the sound spectra N° 1 e 2;
$X_w$ is the Insulation Index calculated from R, $D_n$ or $D_{nT}$ values;
$X_{Aj}$

$$X_{Aj} = -10 \cdot \log_{10} \sum_i 10^{\frac{L_{ij} - X_i}{10}} \quad [dB]$$

where:

- *i* is the subscript for the one-third-octave bands 100 Hz to 3150 Hz or the octave bands 125 Hz to 2000 Hz;
- $L_{ij}$ are the levels of the sound level spectra to calculate the adaptation terms at the frequency i for the spectrum j;
- $X_i$ is the transmission loss $R_i$, or apparent transmission loss, or the normalized level difference $D_{n,i}$, or standardized level difference $D_{nT,i}$, at the measuring frequency i, given to one decimal place.

Calculate the quantity, $X_{Aj}$, with sufficient accuracy and round the result to an integer.2) The resulting spectrum adaptation term is an integer by definition and shall be identified in accordance with the spectrum used, as follows:

C when calculated with spectrum No. 1 (A-weighted pink noise);

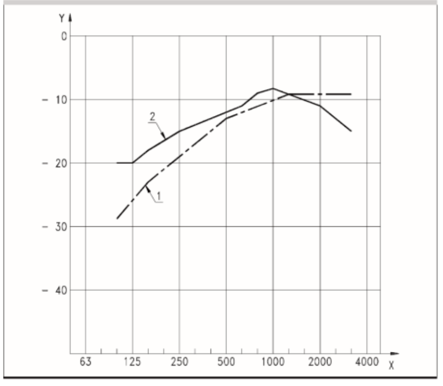
$C_{tr}$ when calculated with spectrum No. 2 (A-weighted urban traffic noise).

## Airborne Sound Insulation Indices – EN ISO 717-1

Sound level spectra to calculate the adaptation terms

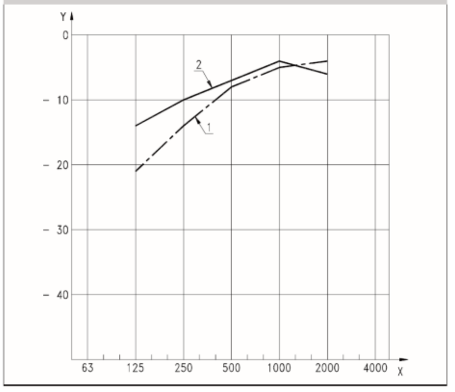
Sound level spectra to calculate the spectrum adaptation terms for one-third octave band values

Key
1 spectrum No. 1 to calculate C
2 spectrum No. 2 to calculate $C_{tr}$
X Frequency in HZ
Y $L_{ij}$ in dB




Sound level spectra to calculate the spectrum adaptation terms for octave band values

Key
1 spectrum No. 1 to calculate C
2 spectrum No. 2 to calculate $C_{tr}$
X Frequency in HZ
Y $L_{ij}$ in dB








## Airborne Sound Insulation Indices – EN ISO 717-1

Frequency reference values and sound spectra in one-third-octave bands and octave bands reference values to calculate the spectrum adaptation terms C e $C_{tr}$.

| Frequency Hz | Reference Values[dB] one-third-octave band | octave band |
|---|---|---|
| 100 | 33 | |
| 125 | 36 | 36 |
| 160 | 39 | |
| 200 | 42 | |
| 250 | 45 | 45 |
| 315 | 48 | |
| 400 | 51 | |
| 500 | 52 | 52 |
| 630 | 53 | |
| 800 | 54 | |
| 1 000 | 55 | 55 |
| 1 250 | 56 | |
| 1 600 | 56 | |
| 2 000 | 56 | 56 |
| 2 500 | 56 | |
| 3 150 | 56 | |

| Frequency | Sound Level, $L_{ij}$, [dB] | | | |
|---|---|---|---|---|
| | spectrum N° 1 to calculate C | | spectrum N° 2 to calculate $C_{tr}$ | |
| Hz | one-third-octave band | octave band | one-third-octave band | octave band |
| 100 | -29 | | -20 | |
| 125 | -26 | -21 | -20 | -14 |
| 160 | -23 | | -18 | |
| 200 | -21 | | -16 | |
| 250 | -19 | -14 | -15 | -10 |
| 315 | -17 | | -14 | |
| 400 | -15 | | -13 | |
| 500 | -13 | -8 | -12 | -7 |
| 630 | -12 | | -11 | |
| 800 | -11 | | -9 | |
| 1 000 | -10 | -5 | -8 | -4 |
| 1 250 | -9 | | -9 | |
| 1 600 | -9 | | -10 | |
| 2 000 | -9 | -4 | -11 | -6 |
| 2 500 | -9 | | -13 | |
| 3 150 | -9 | | -15 | |

## Airborne Sound Insulation Indexes – EN ISO 717-1 : Statement of Performance

- **Statement of performance of building elements**
  the appropriate evaluation index, $R_w$, $R'_w$, $D_{n,w}$ o $D_{nT,w}$ , is reported with both the two spectrum adaptation terms, C e $C_{tr}$ , in parentheses, separated by a semicolon;

  EXAMPLE:

  $R_w$ (C; $C_{tr}$) = 43 (0; - 4) dB

- **Statement of requirements and of performance of buildings**
  Requirements shall be given as the sum of the required evaluation index and the relevant spectrum adaptation term.

  EXAMPLES:

  $D_{nT,w} + C_{tr} > 45$ dB (for facades)

  or

  $R'_w + C > 54$ dB (between rooms or dwellings)



## Indices required to verify the passive acoustic requirements of buildings



The required indices are:

- $R'_w$ : **Weighted Apparent Sound Reduction Index**, which is:
  – R′(500 Hz) apparent transmission loss that is obtained at 500 Hz from the reference curve after repositioning to respect the unfavourable deviations limitation
- $D_{2m,n,T,w}$ **Facade Weighted Standardized Level Difference Index**, which is :
  – $D_{2m,n,T}$(500 Hz) Facade Weighted Standardized Level Difference that is obtained at 500 Hz from the reference curve after repositioning to respect the unfavourable deviations limitation

## Correlations for the estimate of $R_w$ Index (at 500 Hz)



*Sound Reduction Index/ Single Wall / Brick (IEN):*

$R_w = 16 \log_{10}(m') + 7$ **[experimental relation 1]**

Walls made of solid or hollow brick, plastered,

Requirement: mass per unit area: $80 \le m' \le 400$ kg/m$^2$

*Sound Reduction Index/ Single Wall / Brick(UNIVERSITA FERRARA):*

$R_w = 18,1 \log_{10}(m') + 2,9$ **[experimental relation 2]**

Walls made of solid or hollow brick, plastered.

Requirement: mass per unit area: $80 \le m' \le 500$ kg/m$^2$

*Sound Reduction Index/ Single Wall / Gypsum Board. (CSTB):*

$R_w = 13,3 \log_{10}(m') + 12$ **[experimental relation 3]**

Walls made of cladded gypsum boards.

Requirement: mass per unit area: $m' \le 150$ kg/m$^2$



## Other available correlations



*Sound Reduction Index/ Single Wall / Brick and Cement Floor* (IEN):

$R_w = 23 \log_{10}(m') - 8$ **[experimental relation 9]**

Brick and cement floor made of hollow brick blocks (pignatte), interspersed with beams or joists of reinforced concrete

Requirement: mass per unit area: $250 \le m' \le 500$ kg/m$^2$

*Sound Reduction Index/ Single Wall / Interlocking H shaped Lightened Brick Blocks* (SPAGNOLO):

$R_w = 28,4 \log_{10}(m') - 19,3$ **[experimental relation 4]**

Walls made of interlocking H shaped lightened brick blocks, plastered.
Requirement: mass per unit area: $300 \le m' \le 500$ kg/m$^2$

*Sound Reduction Index/ Single Wall / Concrete Blocks*:

$R_w = 25,1 \log_{10}(m') - 7$ **[experimental relation 6]**

Walls made of concrete blocks. Requirement:

mass per unit area: $60 \le m' \le 200$ kg/m$^2$ ; $0,08 < S < 0,33$ [m]

## Other available correlations

*Sound Reduction Index/ Single Wall / Expanded Clay Blocks*:

$R_w = 27{,}4 \log_{10}(m') - 14{,}5$ **[experimental relation 5]**

Walls made of in expanded clay blocks. Requirements :

| | |
|---|---|
| mass per unit area: | $115 \le m' \le 450$ kg/m² |
| mixture density: | $750 \le \rho \le 1600$ kg/m³ |
| blocks hollows percentage: | $0 \le \% \le 40$ |
| Total thickness: | $0{,}11 \le s \le 0{,}33$ m |
| interspace (if applicable): | not filled |

*Sound Reduction Index/ Single Wall / Gypsum Blocks*:

$R_w = 21{,}4 \log_{10}(m') - 2$ **[experimental relation 7]**

Walls made of gypsum blocks,

Requirement: mass per unit area: $70 \le m' \le 110$ kg/m² ; $0{,}08 < Sp < 0{,}1$ [m]





## Other available correlations

*Sound Reduction Index/ Single Wall / Gasbeton:*

$R_w = 21{,}5 \log_{10}(m') + 2{,}6$ **[experimental relation 8]**

Walls made of Gasbeton bricks,

Requirement: mass per unit area: $70 \le m' \le 110$ kg/m² ; $0{,}08 < S < 0{,}1$ [m]

*Sound Reduction Index/ Double Wall / Bricks (IEN):*

$R_w = 16 \log_{10}(m') + 10$ **[experimental relation 10]**

Walls made of solid or hollow brick, plastered.

Requirements:

| | |
|---|---|
| mass per unit area: | $80 \le m' \le 400$ kg/m² |
| interspace: | $e \ge 50$ mm |

interspace : filled, albeit partially, with sound-absorbing porous fibrous material

## Other available correlations



*Sound Reduction Index/ Double Wall / Bricks :*

$R_w$ = - 9,5 + 23,7 $\log_{10}(m')$ + 6,2 $\log_{10}(1 + e)$**[experimental relation 11]**

Double walls made of solid or hollow bricks, plastered. Requirements:

mass per unit area: $80 \leq m' \leq 400$ kg/m$^2$

interspace: $e \geq 50$ mm

*Sound Reduction Index/ Double Wall / Gypsum board / Single Frame (DIN) :*

$R_w = 20 \log_{10}(m') + 10 \log_{10}(d) + e + 5$ **[experimental relation 12]**

Double walls made of cladded gypsum boards for single frame partitions. Requirements:

mass per unit area: $m' \leq 70 - 80$ kg/m$^2$

Total thickness: $6 - 8 \leq s \leq 25 - 30$ cm

Thickness of fibrous/porous sound-absorbing material panel inside the cavity: $e \leq 6 - 8$ cm



## Other available correlations



*Sound Reduction Index/ Double Wall / Gypsum board / Separated frames (DIN):*

$R_w = 20 \log_{10}(m') + 10 \log_{10}(d) + e + 10$ **[experimental relation 13]**

Double walls made of cladded gypsum boards with two separated frames. Requirements:

mass per unit area: $m' \leq 70 - 80$ kg/m$^2$

Total thickness: $6 - 8 \leq s \leq 25 - 30$ cm

Thickness of fibrous/porous sound-absorbing material panel inside the cavity: $e \leq 6 - 8$ cm

*Sound Reduction Index/ Double Wall / Gypsum board / Single frame – single slab on each side (DIN):*

$R_w = 11 + 14 \log_{10}(m') + 10 \log_{10}(1 + d) + 10 \log_{10}(1 + e)$ **[experimental relation 14]**

Double walls made of cladded gypsum boards with single frame – one single board each side.

## Other available correlations

*Sound Reduction Index/ Double Wall / Gypsum board / Single frame – multiple slabs on each side (DIN):*

$R_w = 1 + 16{,}5 \log_{10}(m') + 14{,}8 \log_{10}(1 + d) + 13{,}9 \log_{10}(1 + e)$ **[experimental relation 15]**

Double walls made of cladded gypsum boards with single frame.

*Sound Reduction Index/ Double Wall / Gypsumboard / Separated frames - multiple slabs on each side (DIN):*

$R_w = 20{,}4 + 6{,}42 \log_{10}(m') + 21{,}3 \log_{10}(1 + d) + 8{,}27 \log_{10}(1 + e)$ **[experimental relation 16]**

Double walls made of cladded gypsum boards with separated frames and multiple boards on each side.





# Impact sound

(pounding, etc.)

**Normalized impact sound pressure level**:

sound pressure level in a specific frequency band in the receiving room when the floor under test is excited by a **Standardized Impact Sound Source**, normalized using the equivalent sound absorption area

$$L'_n = L_P + 10 \cdot \log_{10}\left(\frac{A}{A_0}\right)$$

where

$L_p$ is the measured sound pressure level in the receiving room

$A_0$ is the reference equivalent sound absorption area (=10 m$^2$ ISO 140)

$A$ is the equivalent sound absorption area of receiving room





**Standardized Impact Sound Pressure Level**:

sound pressure level in a specific frequency band in the receiving room when the floor under test is excited by a **Standardized Impact Sound Source**, standardized using

$$L'_{nT} = L_P - 10 \cdot \log_{10}\left(\frac{T_{60}}{T_0}\right)$$

dove

$L_p$ is the measured sound pressure level in the receiving room

$T_0$ is the reference value of the reverberation time (=0,5 s )

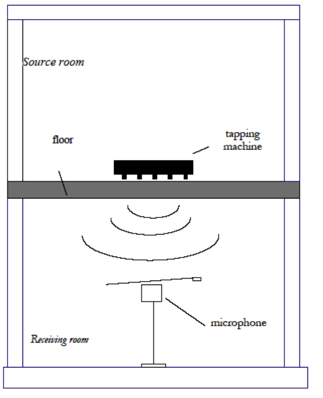
$T_{60}$ is the value of the reverberation in the receiving room

## Impact Sound Insulation Index – EN ISO 717-2

The Impact Sound Insulation Index is defined as the value in dB at 500 Hz obtainable from the reference spectrum repositioning against the measured spectral values of the sound pressure level in the receiving room, when:

**the sum of unfavourable deviations is as large as possible, but not more than 32,0 dB, for 1/3 octave bands, or 10,0 for octave bands analysis**

An unfavourable deviation at a particular frequency occurs when the result of measurements is **greater than** the reference value. Only the unfavourable deviations shall be taken into account.



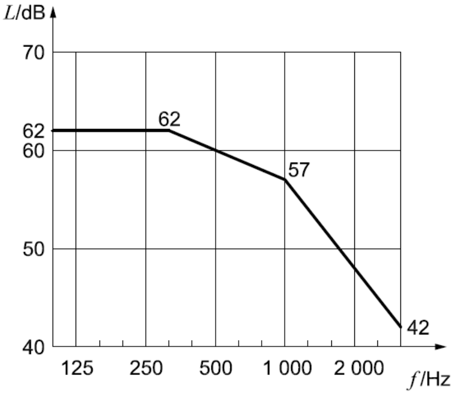





## Impact Sound Insulation Index – EN ISO 717-2

Curve of reference values for impact sound, one-third-octave bands
Key
*f* frequency in Hz
*L* level

$$\Delta Y_{1/3oct} = \sum_i \max\left[0; Y_{meas} - Y_{ref}\right]_i < 32$$

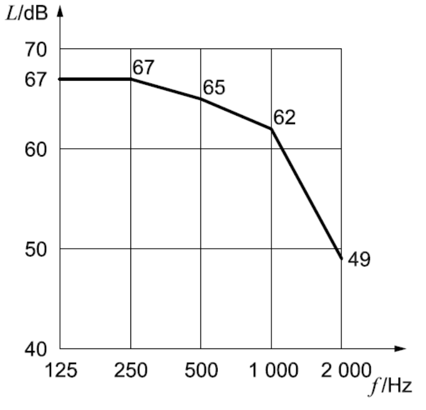



**sum of unfavourable deviations is as large as possible, but not more than 32,0 dB, measurement in one-third-octave bands**

## Impact Sound Insulation Index – EN ISO 717-2

Curve of reference values for impact sound, octave bands
Key
*f* frequency in Hz
*L* level

$$\Delta Y_{oct} = \sum_i \max\left[0; Y_{meas} - Y_{ref}\right]_i < 10$$




**sum of unfavourable deviations is as large as possible, but not more than 10,0 dB, measurement in octave bands**





## Impact Sound Insulation Index – EN ISO 717-2

Reference values for One-third octave bands and Octave bands

| Frequency | Reference values dB | |
|---|---|---|
| Hz | One-third-octave bands | Octave bands |
| 100<br>125<br>160 | 62<br>62<br>62 | 67 |
| 200<br>250<br>315 | 62<br>62<br>62 | 67 |
| 400<br>500<br>630 | 61<br>60<br>59 | 65 |
| 800<br>1 000<br>1 250 | 58<br>57<br>54 | 62 |
| 1 600<br>2 000<br>2 500 | 51<br>48<br>45 | 49 |
| 3 150 | 42 | |

# Service Systems Noise



## Sound contribution of the plants



The noise produced by a service system inside the internal environment can be calculated as:

$$L_p(r) = L_{W,S} + 10 \cdot \log_{10}\left(\frac{Q}{4\pi\, r^2} + \frac{4}{R^*}\right)$$

$$\text{with} \qquad R^* = \frac{S \cdot \alpha_m}{1 - \alpha_m} \qquad \textbf{room constant}$$

where

$L_{W,S}$ is the sound power level of the apparatus

$Q$ is the directivity factor of the sound source

$r$ is the distance of the receiver from the source

## Indices required to verify the passive acoustic requirements of buildings



**Noise of service systems discontinuously operated - $L_{AS,max}$**

- is the MAXIMUM value of the measured sound level in a different environment than the one where the noise originates; this value is equal to 35 dBA.

**Noise of service systems continuously operated - $L_{Aeq}$**

- is the AVERAGE value of the measured sound level in a different environment than the one where the noise originates; this value is equal to 35 dBA for dwellings.



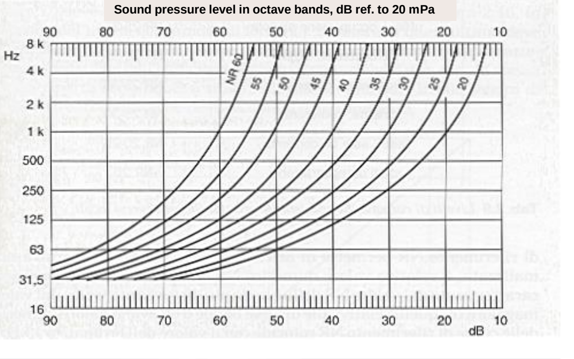
## Index NR (*Noise Rating*)



The sound level produced by the plant is A-weighted → dB(A)
Such A-weighted noise spectrum due to the system is then compared with standardized NR curves. The attributed NR index is that of iso-NR curve which it is always higher than the measured noise spectrum.

| ambient | tolerability |
|---|---|
| heavy factories | NR 55-75 |
| read factories | NR 45-65 |
| sport facilities | NR 35-50 |
| restaurants, bars | NR 35-45 |
| office, single occupancy | NR 25-35 |
| libraries, classrooms | NR 30-35 |
| hospitals, hospital stays | NR 25-30 |
| cinemas, conference rooms | NR 25-30 |
| theatres, concert halls | NR 20-25 |
| recording studios | NR 20 |

**Acceptable noise level for different spaces**



# exercise





1. Estimate the Sound Reduction. using the “Mass Law ” in 1/3 octave band for a wall with a mass $m'$ = 140 kg/m$^2$, for a $m'$ = 280 kg/m$^2$ and for a mass $m'$ = 70 kg/m$^2$

- normal incidence $R_0$
- oblique incidence with incidence angle $\theta = 45°$ $R_{\theta\,\alpha\nu\delta}$ $\theta = 30°$
- diffuse or quasi-diffuse sound field $R_{diff}$

## Sound Reduction Index estimation: "Mass Law "

In the linearity range between $R$ and $f$ (frequency), the first can be given as function of the second as :

**normal incidence**

$$R_0 = 20 \cdot \log_{10}\left(f \cdot M_S\right) - 42{,}3 \qquad [dB]$$

**oblique incidence with incidence angle $\theta$**

$$R_\theta = 20 \cdot \log_{10}\left(f \cdot M_S \cdot \cos(\theta)\right) - 42{,}3 \qquad [dB]$$

**diffuse or quasi-diffuse sound field**

$$R_{diff} = R_0 - 10 \cdot \log_{10}\left(0{,}23 R_0\right) \qquad [dB]$$

$$R_{diff} = R_0 - 5 \qquad [dB] \qquad \text{for } R_0 > 15\ dB \ \text{ and } \ \theta_{i,\lim} = 78°$$





Estimate the *the Sound Reduction Index* using three available correlations, for a wall made of bricks m'=140 kg/m$^2$ as follows:

<u>*Sound Reduction Index Brick (IEN)*</u>

$R_w$ = 16 $\log_{10}(m')$ + 7 **[experimental relation 1]**

Walls made of solid or hollow brick, plastered,

Requirement: mass per unit area: 80 ≤ $m'$ ≤ 400 kg/m$^2$

<u>*Sound Reduction Index/ Single Wall / Brick(UNIVERSITA FERRARA):*</u>

$R_w$ = 18,1 $\log_{10}(m')$ + 2,9 **[experimental relation 2]**

Walls made of solid or hollow brick, plastered.

Requirement: mass per unit area: 80 ≤ $m'$ ≤ 500 kg/m$^2$

<u>*Sound Reduction Index/ Single Wall / Gypsum Board. (CSTB):*</u>

$R_w$ = 13,3 $\log_{10}(m')$ + 12 **[experimental relation 3]**

Walls made of cladded gypsum boards.

Requirement: mass per unit area: $m'$ ≤ 150 kg/m$^2$