LECTURE 2
Airborne sound insulation

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Lecture 2 – Airborne sound insulation

”The sound transmission capability of different building materials varies, and things get complicated when you consider the fact that the same material also transmits different sound wavelengths differently; furthermore, one must consider whether the structure is single or comprised of several layers.”

M. Sc. U. Varjo 1938
Basics
### Background noise level

\[ L_{A,eq} = 35 \text{ dB} \]

<table>
<thead>
<tr>
<th>Ilmaäänen-eristysluku ( R'_{w} ) (dB)</th>
<th>Kokemus puheäänistä naapuritilassa</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; 60</td>
<td>voimakas huuto kuuluu seinän läpi, sanoista ei saa selvää</td>
</tr>
<tr>
<td>&gt; 55</td>
<td>voimakas puhe ei kuulu seinän läpi</td>
</tr>
<tr>
<td>&gt; 50</td>
<td>voimakas puhe kuuluu seinän läpi, sanoista ei saa selvää</td>
</tr>
<tr>
<td>&gt; 45</td>
<td>normaali keskusteluääni ei kuulu seinän läpi</td>
</tr>
<tr>
<td>&gt; 40</td>
<td>normaali keskusteluääni kuuluu seinän läpi, sanoista ei saa selvää</td>
</tr>
<tr>
<td>&gt; 35</td>
<td>normaali keskusteluääni kuuluu seinän läpi, sanoista saa selvää, mutta ääni ei halitaa keskittymistä</td>
</tr>
<tr>
<td>&lt; 30</td>
<td>seinä ei estä kuuntelemasta tapahtumia naapurihuoneesta</td>
</tr>
</tbody>
</table>
Significance of sound insulation
Speech distinction

- Speech distinction between rooms depends on airborne sound insulation and background noise level of the receiving room
- An objective, measurable quantity describing speech distinction (intelligibility) is the Speech Transmission Index, STI (puheensiirtoindeksi)
- STI has values between 0...1; STI = 0 meaning that none of the syllables in speech can be distinguished and STI = 1 that distinction of syllables is perfect
- The relation between STI and weighted sound reduction index (ilmaääneneristystysluku)...

Significance of sound insulation
Speech distinction

<table>
<thead>
<tr>
<th>STI value</th>
<th>Puheen erotettavuus</th>
<th>Esimerkkejä tiloista</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alle 0.30</td>
<td>Kelvoton</td>
<td>Kivistö</td>
</tr>
<tr>
<td>0.30 ... 0.45</td>
<td>Huono</td>
<td>Kuirkko</td>
</tr>
<tr>
<td>0.45 ... 0.60</td>
<td>Väältävä</td>
<td>Kaiutava auditoro tai konsertissä</td>
</tr>
<tr>
<td>0.60 ... 0.75</td>
<td>Hyvä</td>
<td>Hyvin suunniteltu suuri auditorio</td>
</tr>
<tr>
<td>Yli 0.75</td>
<td>Erinomainen</td>
<td>Hyvin suunniteltu lucatihuone tai pieni auditorio</td>
</tr>
</tbody>
</table>

The figures assume a normal level of speech, A-weighted sound level 65 dB
Definition of sound reduction index

\[ R = 10 \log \left( \frac{W_1}{W_2} \right) \]
Definition of sound reduction index
Definition using the transmission coefficient

\[ \tau = \frac{W_t}{W_i} \]

\[ R = 10 \log \left( \frac{1}{\tau} \right) = 10 \log \left( \frac{W_i}{W_t} \right) \]

<table>
<thead>
<tr>
<th>( \frac{W_t}{W_i} )</th>
<th>R (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>0.1</td>
<td>10</td>
</tr>
<tr>
<td>0.01</td>
<td>20</td>
</tr>
<tr>
<td>0.001</td>
<td>30</td>
</tr>
<tr>
<td>0.0001</td>
<td>40</td>
</tr>
<tr>
<td>0.00001</td>
<td>50</td>
</tr>
<tr>
<td>0.000001</td>
<td>60</td>
</tr>
<tr>
<td>jne</td>
<td>jne</td>
</tr>
</tbody>
</table>
Measurement of sound reduction index

Laboratory measurement:

\[ R = L_1 - L_2 + 10 \log \frac{S}{A} \]

Field measurement:

\[ R' = L_1 - L_2 + 10 \log \frac{S}{A} \]
Weighted sound reduction index
Determination from the reference curve

ISO 717-1 reference curve, shape constant
(based on variation of hearing sensitivity and speech spectrum)
Weighted sound reduction index (ilmaääneneristysluku)

- Weighted sound reduction index (ilmaääneneristysluku) $R_w^*$ is a single-number quantity which is determined from the measured or calculated sound reduction index according to ISO 717-1 between one-third octave bands 100 – 3150 Hz
  - Reference curve (vertailukäyrä) (ISO 717-1) is moved with 1 dB steps to such a position that the sum of unfavourable deviations (ei-toivottu poikkeama) to the reference curve is as large as possible but not more than 32,0 dB (when measurement has been done in 16 one-third octave bands) or 10,0 dB (when the measurement has been done in 5 octave bands)
  - Unfavourable deviation: measured or calculated sound reduction index is smaller than the value of the reference curve at a certain frequency
- $R_w^*$ corresponds to field measurement (kenttämittaus) ja $R_w$ to laboratory measurement
- Terminology in English and Finnish:
  - $R_w^*$: apparent weighted sound reduction index (ilmäääneneristysluku)
  - $R_w$: weighted sound reduction index (ilmäääneneristysluku)
Weighted sound reduction index
Determination from the reference curve

ISO 717-1
reference curve

Figure 2 — Curve of reference values for airborne sound, octave bands
Weighted sound reduction index  
Determination from the reference curve

ISO 717-1 reference curve values

<table>
<thead>
<tr>
<th>Frequency (Hz)</th>
<th>One-third-octave bands</th>
<th>Reference values, dB</th>
<th>Octave bands</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>33</td>
<td>36</td>
<td>36</td>
</tr>
<tr>
<td>125</td>
<td>36</td>
<td>39</td>
<td></td>
</tr>
<tr>
<td>160</td>
<td>42</td>
<td>45</td>
<td>45</td>
</tr>
<tr>
<td>200</td>
<td>48</td>
<td>51</td>
<td></td>
</tr>
<tr>
<td>250</td>
<td>45</td>
<td>52</td>
<td>52</td>
</tr>
<tr>
<td>315</td>
<td>48</td>
<td>53</td>
<td>53</td>
</tr>
<tr>
<td>400</td>
<td>51</td>
<td>54</td>
<td>54</td>
</tr>
<tr>
<td>500</td>
<td>52</td>
<td>56</td>
<td>56</td>
</tr>
<tr>
<td>630</td>
<td>53</td>
<td></td>
<td></td>
</tr>
<tr>
<td>800</td>
<td>54</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1000</td>
<td>55</td>
<td></td>
<td>55</td>
</tr>
<tr>
<td>1250</td>
<td>56</td>
<td></td>
<td>56</td>
</tr>
<tr>
<td>1600</td>
<td>56</td>
<td></td>
<td>56</td>
</tr>
<tr>
<td>2000</td>
<td>56</td>
<td></td>
<td>56</td>
</tr>
<tr>
<td>2500</td>
<td>56</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3150</td>
<td>56</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Field vs. laboratory measurement

• The sound reduction index measured in the field ($R'_w$) is in practice always lower than that measured in laboratory ($R_w$), because:
  – In a building sound traverses not only through the separating structure, but also via flanking structures as *flanking transmission* (*sivutiesiirtymä*)
  – Holes and other sound leaks due to, e.g., installation errors deteriorate sound insulation

• Difference between $R'_w$ and $R_w$:
  – As large as 20 dB, if the structure contains sound leaks
  – 5-10 dB if flanking transmission is high
  – below 1 dB, if structures are properly sealed and flanking transmission has been eliminated
Field vs. laboratory measurement

- Example: double-leaf wooden door measured in the field and in laboratory
- Difference in sound reduction index caused by poor sealing
Spectrum adaptation terms (spektripainotustetermit)

- The shape of ISO 717-1 reference curve is based on the variation of hearing sensitivity at different frequencies and the spectrum of speech
- Thus the weighted sound reduction index $R'_w$ primarily describes the ability of structure to isolate speech!
  → in order to describe sound insulation against, e.g., traffic noise other descriptors are needed because traffic noise has more sound energy at lower frequencies
- Spectrum adaptation terms:
  - $C_t$: traffic noise
  - $C$: railway and airplane traffic
Spectrum adaptation terms

- $R'_{w} + C_{tr}$: weighted sound reduction index against road traffic noise (ilmaäääneneristysluku tieliikennemelua vastaan)
- $R'_{w} + C$: weighted sound reduction index against railway / airplane traffic noise (ilmaäääneneristysluku lento-/raideliikennemelua vastaan)

- These describe quite well how many decibels the structure is able to cut from the A-weighted traffic noise level
- The values are needed in the design of facade (and roof) sound insulation (ulkovaipan ääneneristystyksen suunnittelu)
### Spectrum adaptation terms
ISO 717-1 definition

<table>
<thead>
<tr>
<th>Type of noise source</th>
<th>Relevant spectrum adaptation term</th>
</tr>
</thead>
<tbody>
<tr>
<td>Living activities (talking, music, radio, tv)</td>
<td></td>
</tr>
<tr>
<td>Children playing</td>
<td></td>
</tr>
<tr>
<td>Railway traffic at medium and high speed¹</td>
<td></td>
</tr>
<tr>
<td>Highway road traffic &gt; 80 km/h¹</td>
<td></td>
</tr>
<tr>
<td>Jet aircraft, short distance</td>
<td></td>
</tr>
<tr>
<td>Factories emitting mainly medium and high frequency noise</td>
<td></td>
</tr>
<tr>
<td>Urban road traffic</td>
<td></td>
</tr>
<tr>
<td>Railway traffic at low speeds¹</td>
<td></td>
</tr>
<tr>
<td>Aircraft, propeller driven</td>
<td></td>
</tr>
<tr>
<td>Jet aircraft, large distance</td>
<td></td>
</tr>
<tr>
<td>Disco music</td>
<td></td>
</tr>
<tr>
<td>Factories emitting mainly low and medium frequency noise</td>
<td></td>
</tr>
</tbody>
</table>

1) In several European countries, calculation models for highway road traffic noise and railway noise exist, which define octave band levels; these could be used for comparison with spectra Nos. 1 and 2.

C
(spectrum No. 1)

C_y
(spectrum No. 2)
Sound insulation of small elements

- The sound insulation of small structural elements (area of about 0.2 m² or less), e.g. a fresh air vent in a facade, is defined by the normalised unit insulation $D_{n,e}$:

$$D_{n,e} = \Delta L_{p,1} - \Delta L_{p,2} + 10 \log_{10} \frac{A_0}{A_2}$$

where $A_0 = 10$ m² and $A_2$ = absorption area of the receiving room.

- The definition means that the sound insulation of small elements is normalised to correspond to 10 m² wall area; this is done because using the real area $S$ of the element in the calculation would lead to very low sound insulation values which would be misleading when compared to the sound insulation of a wall structure.

- When $D_{n,e}$ values are used in calculations, their area must be set to 10 m².
Theory and modelling
Basic structural types

1. Single structure
2. Double structure
3. Triple structure
4. Lightweight sandwich structure
Single plates
Wave types

Kvasipitkätäisälto (quasi-longitudinal)
Leikkausaalto (shear)
Tavutusaalto (bending)
Rayleigh -aalto

Poikitsaaliikkeen amplitudi lienee.
Single plates
Wave types

- **Bending waves** (taivutusaallot) and shear waves (leikkausaallot) are the most important wave type contributing to airborne sound radiation of plates, because in those wave types the plate moves in perpendicular direction to air, thus causing interaction with the nearby air molecules.

- In plates with thickness < 30 mm and mass < 100 kg/m² bending waves dominate sound radiation up to 5000 Hz, which covers the range used in building acoustical measurements (100 - 3150 or 50 - 5000 Hz).

- Shear waves have some effect on sound radiation of thick plates.

- Other wave types (Rayleigh and quasi-longitudinal waves) can be considered as insignificant to airborne sound radiation and, thus, can be neglected in calculations of sound reduction index.
Single plates
Wave types

- Bending waves are *dispersive*, i.e., the phase velocity (speed) of bending waves depends on frequency (the only wave type to which this applies):

\[ c_B = 4 \sqrt{\frac{\omega^2 B}{m'}} \]

- Where \( \omega \) is angular frequency (\( 2\pi f \)), \( B \) is bending stiffness and \( m' \) is surface mass

- For comparison, phase velocity of longitudinal sound waves in air is given by

\[ c_0 = 331 + 0.6T \]

- where \( T \) is air temperature (for \( T = 20\^\circ C \), \( c_0 = 343 \text{ m/s} \))
Single plates
Typical behaviour

100-3150 Hz
Single plates
Mass law (massalaki)

• Sound reduction index (abbreviated as SRI in these slides) according to mass law depends on
  – Mass per unit area or surface density of the structure \( m' \) [kg/m\(^2\)]
  – Frequency \( f \) [Hz]

• Sound reduction index according to mass law:
  \[ R_0 = 20 \log m' + 20 \log f - 48 \]

\[ \rightarrow \text{sound reduction index increases 6 dB, when mass or frequency doubles} \]

• But this is not true in the entire frequency region…
Single plates
Prediction model for thin single plates

• The SRI of thin plate (d ~ 0.4...25 mm, m` ~ 2...50 kg/m²) can be calculated using the following equations (RIL243):

\[
R = \begin{cases} 
20\log_{10} m'f - 48 \text{ dB} & \text{kun } f < \frac{1}{2} f_c \\
20\log_{10} m'f + 10\log_{10} \left[ \eta \left( \frac{f}{f_c} - 1 \right) \right] - 44 \text{ dB} & \text{kun } f \geq f_c 
\end{cases}
\]

where \( f_c \) is the critical frequency (of coincidence phenomenon) (koinsidenssin rajataajuus) and \( \eta \) is the loss factor (häviökerroin)

• According to the above, mass law applies up to half the critical frequency above which the sound insulation behaviour of the plate changes
Single plates
Coincidence phenomenon

- Airborne sound (longitudinal wave) causes a bending wave in the plate
- Coincidence occurs when the longitudinal sound wave in air hitting the plate at a certain angle and the bending wave in the plate are in phase, and thus sound penetrates the structure easily
- Critical frequency is the lowest frequency at which the coincidence phenomenon occurs and corresponds to sound incidence angle $\theta = 90^\circ$, i.e. parallel to the plate (ääni saapuu levyyyn sen pinnan suuntaisesti)
- Coincidence occurs at the higher frequency, the more perpendicular to the plate is the sound incidence angle
Single plates
Coincidence phenomenon

• The frequency at which the phase velocity of bending waves in a plate equals the phase velocity of longitudinal waves in air, $c_0 = c_B$, is the critical frequency

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

where $B$ is the bending stiffness of the plate, $E$ is elastic modulus, $h$ is plate thickness, $\mu$ is Poisson`s ratio, $c_0$ is the speed of sound, $m'$ is surface density

$\rightarrow f_c$ is the lower, the higher is the elastic modulus and material thickness and the lower is surface density

• Heavy and rigid structure, such as thick concrete wall has low $f_c$, whereas lightweight plate such as gypsum board has high $f_c$
Single plates
Measurement vs. prediction (calculation)

Coincidence "dip"

Gypsum board
N 13 mm
Single plates
Critical frequencies of materials

\( f_c \):\textsubscript{n} should lie outside this region in order to achieve a high value of \( R_w \)
Single plates
Critical frequencies of plates

Graph showing critical frequencies for different materials (MDF, chipboard, plywood, gypsum board, steel) as a function of thickness [mm]. The graph includes data points and trend lines, with annotations for each material type.

[Remes 2009]
Single plates
Loss factor, Poisson`s ratio

• The (total) loss factor in the calculation model, $\eta$, describes how vibration is attenuated in the structure
• Loss factor depends on radiation losses, coupling losses and internal losses (the coupling of plate to studding, for example)
• Loss factor depends on frequency but affects sound insulation only above the critical frequency
• A constant value of $\eta = 0.02$ can be used for building boards attached from the sides
• Following values can be used for the Poisson`s ratio:
  – $\mu = 0.25$ (building boards, concrete, glass)
  – $\mu = 0.30$ (metals)
  – $\mu = 0.40$ (rubber and bitumen)
Single plates
Other transition frequencies

Sound reduction index of chipboard 22 mm using the model by Kristensen & Rindel
Single plates
The prediction model of Kristensen & Rindel

- The sound reduction index of a single plate, calculated in four frequency regions [Kristensen, Rindel 1989]:

\[
R \approx \begin{cases} 
R_0 - 10 \log_{10} \left(2\sigma_d\right) + 20 \log_{10} \left(1 - \left(\frac{f}{f_c}\right)^2\right), f < f_c \\
R_0 + 10 \log_{10} \eta + 10 \log_{10} \left(\frac{f}{f_c}\right) - 2, f \geq f_c \\
R_0 + 10 \log_{10} \left(\eta \left(\frac{f}{f_c}\right)\right) - 10 \log_{10} \left(\frac{f}{5f_h} + \sqrt{\left(\frac{f}{5f_h}\right)^2 + 1}\right) - 2, f > f_h \\
R \approx R_0 - 10 \log_{10} \left(2\sigma_d\right) + 40 \log_{10} \left(\frac{f_{11}}{f}\right), f < f_{11} 
\end{cases}
\]
Single plates
Lowest natural frequency

- The lowest natural frequency (plate supported from the sides):

\[ f_{11} = \frac{c^2}{4f_c} \left( \frac{1}{l_x^2} + \frac{1}{l_y^2} \right) \]

where \( l_x \) and \( l_y \) are plate dimensions

- Usually the lowest natural frequencies are below the frequency range of interest so they need not be considered (<100 Hz; Note: \( R_w \) is determined in the frequency range of 100-3150 Hz)
Single plates
Transition frequency of shear waves

• In addition to bending waves, shear waves occur in thick plates
• Shear waves affect sound reduction index above a transition frequency:

\[ f_h = \frac{1}{f_c} \left( \frac{c_0}{6h} \right)^2 \]

where \( f_c \) is critical frequency and \( h \) is thickness
• In thin plates < 30 mm and < 100 kg/m^2 shear waves do not much occur below 5000 Hz \( \rightarrow \) shear waves do not significantly affect the sound reduction index of thin plates
Single plates
Building boards

Keskitaajuus [Hz]
Ilmaääneneristävyys R [dB]

Teräs 4 mm
Lasi 4 mm
Kipsilevy 13 mm
Puu 23 mm

[Kylläinen 2007]
Single plates
Building boards

Ilmaääneneristävyys $R$ [Hz]

- Teräslevy 2 mm 15.6 kg/m² (36 dB)
- Lastulevy 22 mm 13.9 kg/m² (29 dB)
- Puukuitulevy 12 mm 3.1 kg/m² (23 dB)
- Kipsikartonkilevy, normaali 8.8 kg/m² (28 dB)

Taajuus [Hz]
Sound insulation of building boards

<table>
<thead>
<tr>
<th>Specimen number</th>
<th>Specimen type</th>
<th>Surface mass [kg/m²]</th>
<th>Critical frequency [Hz]</th>
<th>Young’s modulus [Pa] x 10³</th>
<th>Rw</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Plasterboard</td>
<td>5.9</td>
<td>5000</td>
<td>5.4</td>
<td>28</td>
</tr>
<tr>
<td>2</td>
<td>Plasterboard</td>
<td>7.6</td>
<td>3150</td>
<td>4.8</td>
<td>28</td>
</tr>
<tr>
<td>3</td>
<td>Plasterboard</td>
<td>8.8</td>
<td>2500</td>
<td>3.0</td>
<td>28</td>
</tr>
<tr>
<td>4</td>
<td>Plasterboard</td>
<td>11.7</td>
<td>2500</td>
<td>4.5</td>
<td>29</td>
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<tr>
<td>5</td>
<td>Plasterboard</td>
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<td>2000</td>
<td>7.8</td>
<td>31</td>
</tr>
<tr>
<td>6</td>
<td>Minerit</td>
<td>7.7</td>
<td>5000</td>
<td>15</td>
<td>30</td>
</tr>
<tr>
<td>7</td>
<td>Minerit</td>
<td>9.8</td>
<td>3150</td>
<td>9.6</td>
<td>30</td>
</tr>
<tr>
<td>8</td>
<td>Minerit</td>
<td>13.2</td>
<td>3150</td>
<td>15</td>
<td>31</td>
</tr>
<tr>
<td>9</td>
<td>Minerit</td>
<td>14.7</td>
<td>3150</td>
<td>16</td>
<td>33</td>
</tr>
<tr>
<td>10</td>
<td>Minerit</td>
<td>14.8</td>
<td>3150</td>
<td>15</td>
<td>32</td>
</tr>
<tr>
<td>11</td>
<td>Minerit</td>
<td>18.4</td>
<td>2500</td>
<td>15</td>
<td>32</td>
</tr>
<tr>
<td>12</td>
<td>Wood based</td>
<td>7.0</td>
<td>4000</td>
<td>2.9</td>
<td>28</td>
</tr>
<tr>
<td>13</td>
<td>Wood based</td>
<td>9.2</td>
<td>2500</td>
<td>6.3</td>
<td>28</td>
</tr>
<tr>
<td>14</td>
<td>Wood based</td>
<td>10.4</td>
<td>1600</td>
<td>11</td>
<td>26</td>
</tr>
<tr>
<td>15</td>
<td>Wood based</td>
<td>13.8</td>
<td>1600</td>
<td>4.8</td>
<td>28</td>
</tr>
<tr>
<td>16</td>
<td>Wood based</td>
<td>13.9</td>
<td>2000</td>
<td>3.4</td>
<td>30</td>
</tr>
<tr>
<td>17</td>
<td>Wood based</td>
<td>15.0</td>
<td>1250</td>
<td>11</td>
<td>28</td>
</tr>
<tr>
<td>18</td>
<td>Wood fiber board</td>
<td>3.1</td>
<td>8000</td>
<td>0.3</td>
<td>23</td>
</tr>
<tr>
<td>19</td>
<td>Wood fiber board</td>
<td>8.0</td>
<td>4000</td>
<td>0.2</td>
<td>30</td>
</tr>
</tbody>
</table>

[Larm et al. 2006]
Single plates
Heavy masonry structures

![Graph showing the relationship between sound transmission and frequency for different materials.](image-url)

- Betoni 300 mm
- Betoni 180 mm
- Kalkkihiekkakivi 130 mm
- Savitiili 130 mm

[Kylläinen 2007]
## Sound insulation of concrete

<table>
<thead>
<tr>
<th>Concrete [mm]</th>
<th>$R_w (C, C_{tr})$ [dB]</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 mm</td>
<td>50 (-1,-4) dB</td>
</tr>
<tr>
<td>120 mm</td>
<td>53 (-1,-4) dB</td>
</tr>
<tr>
<td>150 mm</td>
<td>57 (-2,-5) dB</td>
</tr>
<tr>
<td>180 mm</td>
<td>60 (-1,-5) dB</td>
</tr>
<tr>
<td>200 mm</td>
<td>61 (-1,-4) dB</td>
</tr>
<tr>
<td>300 mm</td>
<td>68 (-1,-4) dB</td>
</tr>
</tbody>
</table>
Single plates
Lightweight masonry structures

![Graph showing sound absorption levels for different materials](image-url)

- Betoni 60 mm
- Savitiili 85 mm
- Kevytsorabetoni 68 mm
- Kevytbetoni 68 mm

[Kylläinen 2007]
Single plates
Several plates attached together

• The sound reduction index of \( n \) plates (e.g. building boards) attached together loosely with screws or nails can be calculated from the equation:

\[
R_{\text{sum}} = 20 \log_{10} \left( \sum_{i=1}^{n} 10^{R_i/20} \right)
\]

where \( R_i \) is the sound reduction index of single plate (calculated or measured in a laboratory)

• The equation applies only when the plates are attached together with screws or nails; in this case the plates can be considered acoustically independent, that is, the bending stiffnesses and critical frequencies of individual plates do not change significantly.

• If the plates are glued together, the acoustical behaviour of the combination changes and the equation cannot be used reliably.
Double structures
Structural types
Double structures
Double-leaf partition – coupling types

No coupling
Weak coupling
Coupling from sides
Totally coupled
Double structures

Double-leaf partition – sound insulation

- The most important factor affecting the sound reduction index is the coupling type.
**Double structures**  
**Double-leaf partition – sound insulation**

- Depending on the coupling type, the following rules of thumb can be given of the factors that affect sound insulation.
- The sound insulation of a **non-coupled double-leaf partition** (kytkemätön kaksinkertainen levyseinä) improves significantly when
  - Total mass increases (amount of plates)
  - Thickness of air space increases
  - Amount of absorption material in air space increases
- The sound insulation of a **coupled double-leaf partition** (kytketty kaksinkertainen levyseinä) improves when
  - Amount of couplings (studs, railings = rankojen ja kiskojen) decreases
  - Flexibility of couplings increases, i.e., their dynamic stiffness decreases (dynaaminen jäykkyys)
  - Attachment of plates to studs weakens (amount of screws decreases and/or the screwing tension decreases)
Double structures
Double-leaf partition – sound insulation

• The factors listed in the list for coupled partition on the previous slide also affect the sound insulation of non-coupled partition but the effect is not so significant

• Example: in a partition with (stiff) wooden studs the effect of absorption material or airspace thickness on sound insulation is almost negligible compared to a non-coupled partition
Double structures
Modelling principle

1. Modelling of ideal double-leaf partition, resulting SRI-value: $R_{ideal}$
   - totally uncoupled structure
   - perfect cavity absorption

2. Modelling of partition with imperfect cavity absorption, resulting SRI-value: $R_{real}$
   - totally uncoupled structure
   - imperfect cavity absorption

3. Modelling of partition with stiff studs, resulting SRI-value: $R_{br}$
   - coupling between plates via stiff studs
   - imperfect cavity absorption

4. Modelling of partition with flexible studs
Double structures
Calculation model for double-leaf partitions

• Calculation starts with the sound reduction index of an ideal double structure:

\[
R_{\text{ideal}} = \begin{cases} 
20\log_{10}(m_1 + m_2) f - 48 & f < f_{\text{mam}} \\
R_1 + R_2 + 20\log_{10} fd - 29 & f_{\text{mam}} < f < f_i \\
R_1 + R_2 + 6 & f > f_i 
\end{cases}
\]

where \( R_1 \) and \( R_2 \) are the SRIs of plates 1 and 2, \( f_{\text{mam}} \) is the mass-air-mass resonance frequency (massa-ilma-massa resonanssi), \( d \) is cavity thickness, \( f_i \) is the resonance frequency corresponding to cavity thickness.

• In an ideal structure there is no coupling between the plates ("leaves") and the air space is totally sound absorbing.

• \( R_{\text{ideal}} \) is the highest possible value that a double-leaf partition can achieve.
Double structures
Transition frequencies

\[ f_{\text{mam}} = \frac{1}{2\pi} \sqrt{\frac{1.8\rho_0 c_0^2 (m_1 + m_2)}{d m_1 m_2}} \approx 80 \sqrt{\frac{m_1 + m_2}{d m_1 m_2}} \]

\[ f_d = \frac{c_d}{2\pi d} \]

critical frequency (property of the single plate)
resonance frequency corresponding to cavity thickness
Double structures
Mass-air-mass resonance frequency

• The sound reduction index of a double structure is at the lowest at the **mass-air-mass resonance frequency**, and above the frequency sound reduction index increases rapidly

\[ f_{\text{mam}} = \frac{1}{2\pi} \sqrt{\frac{1.8 \rho_0 c_0^2 (m_1 + m_2)}{dm_1 m_2}} \approx 80 \sqrt{\frac{m_1 + m_2}{dm_1 m_2}} \]

• Mass-air-mass resonance: the air between the surface plates (masses) acts as a spring and the plates and air resonate at this frequency causing sound insulation to deteriorate

• A well-designed structure should have a value of \( f_{\text{mam}} \) below 100 Hz, so that the effect of the resonance on \( R_w \) value is rendered insignificant
Double structures
Transition frequency $f_d$

- $f_d$ is a transition frequency, above which sound wavelength is so small compared to the thickness of the airspace, that the airspace no longer acts as a spring.
- At the transition frequency, airspace thickness $d$ is about $1/6$ of the sound wavelength:

$$f_d = \frac{c_d}{2\pi d}$$

- where $c_d$ is the speed of sound in the airspace filling material (usually air in which case $c_d = c_0 = 343$ m/s).
Double structures
Example: ideal structure, airspace thickness

Structure:
- Gypsum board N 13 mm
- Airspace thickness varies, airspace ideally sound absorbing
- Gypsum board N 13 mm

Rw = 42…49 dB
f_{mam} = 85…170 Hz
f_d = 271…1082 Hz
Double structures
Example: ideal structure, number of plates

Ideally absorbing airspace
100 mm

1 plate
2 plates
4 plates
Double structures
Reberberation of the airspace

Effect of the filling ratio of the airspace with sound absorbing material. Non-coupled structure, airspace 125 mm. 0% means that the airpace is empty.
Note: laboratory measurement

(2002 Hongisto V. et. al)
Double structures
Reberberation of the air space

• The function of sound absorption material in the air space is to prevent the reverberation of the air space and the deterioration of sound insulation thus caused.

• If there is no absorption material in the cavity, horizontal and vertical standing waves occur due to which SRI can decrease up to 20 dB.

• An ideal double structure has totally sound absorbing (non-reverberant) cavity ($R_{\text{ideal}}$). The deterioration of SRI caused by non-ideal cavity absorption is taken account of by using the term $R_{\text{real}}$. 
Double structures
Reberberation of the air space

- The airspace absorption in the calculation model of double-leaf partitions is taken into account by adding a correction term $\Delta R_{\text{abs}}$ above limiting frequency $f_1$:

$$ R_{\text{real}} = \begin{cases} 
R_{\text{ideal}}, f < f_1 \\
R_{\text{ideal}} + \Delta R_{\text{abs}}, f \geq f_1 
\end{cases} $$

$$ \Delta R_{\text{abs}} = 10 \log_{10} \alpha_{\text{eff}} $$

- $f_1$ is the lowest cavity resonance, i.e., the frequency below which airspace does not reverberate (i.e., sound waves do not "fit" to resonate in the cavity due to long wavelength)

$$ f_1 = \frac{c_0}{2L} $$

where $L$ is the greater of dimensions airspace width/height
Double structures
Reverberation of the air space

- Reverberation of the airspace occurs only above the lowest airspace resonance frequency $f_1$
- The lowest resonance frequency occurs at a frequency where the longest dimension of the airspace equals half the sound wavelength

$$f_1 = \frac{c_0}{2L}$$

[Hongisto 2003]
Double structures
Sound insulation of a coupled partition

• There is often a coupling between the leaves (plates) of a double-leaf partition due to studding/frame → sound insulation diminishes especially at mid to high frequencies

• In a non-coupled structure all sound goes through the airspace

• In a coupled structure most of the sound goes through the studding and frame
Double structures
Sound insulation of a coupled partition

- The SRI of a double-leaf partition with stiff studs ($R_{br}$) is calculated as follows:

$$R_{br} = \min\left[R_{\text{real}}, R_M + \Delta R_M\right], f > f_{br}$$

$$R_M = 20 \log\left[(m_1 + m_2)f\right] - 48$$

- The deteriorating effect of the coupling (studding) begins above the bridge frequency, $f_{br}$
- Below the bridge frequency, SRI is determined according to previously-described $R_{\text{real}}$ value
- Term $R_M + \Delta R_M$ is the highest value of SRI that a studded partition can have above bridge frequency
Double structures
Sound insulation of a coupled partition

- Bridge frequency $f_{br}$ and term $\Delta R_M$ are calculated from the equations:

$$f_{br} = f_{mam} \left( \frac{\pi bf_c}{2c_0} \left( \frac{m_1}{m_1 + m_2} \right)^2 \right)^{1/4}$$

$$\Delta R_M = 10 \log_{10} (bf_c) + 20 \log_{10} \left( \frac{m_1}{m_1 + m_2} \right) - 18$$

where $b$ is distance between line couplings (viivakytkentä) i.e. studs (eli k-jako) and $f_c$ is the critical frequency
Double structures
Effect of coupling type
Double structures
Effect of coupling type

Calculated values
Studs c/c 600mm, steel studs with low dynamic stiffness as flexible studs, wooden studs as stiff studs
Double structures
Effect of coupling type

Measured values
Studs 100mm, absorbing airspace, 2xgypsum board 13mm on both sides

Puurunko = (stiff) wooden studs
Teräsranka = steel studs
Joustava teräsranka = flexible steel studs

Puu ranka
Teräsranka
Joustava teräsranka

Keskitaajuus [Hz]
Ilmaäänentävyys R [dB]
Double structures
Effect of mass (number of plates)

[Graphs showing sound reduction index vs. frequency for different structures with varying number of plates and mass effects.]
Double structures
Effect of airspace filling material

Kaksinkertaisen rakenteen tyhjässä ilmatilassa syntyy ilman ominaisvärähtelyjä. Ilmavälin pituus- ja pystysuunnassa niiden ominais- taajuudet ovat matalia ja leveyssuunnassa korkeita.
Double structures
Effect of airspace thickness

[Remes 2009]
Double structures
Effect of airspace filling ratio
Double structures
Effect of c/c distance of studs

c/c distance of studs is $b = 550/1100$ mm.
"kytkemätön" = non-coupled structure (given for comparison)
Note: laboratory measurement

(2002 Hongisto V. et. al)
Double structures
Effect of screw density

$c/c$ distance of studs is $b = 300$ mm. $bs = c/c$ distance of screws.
"kytkemätön" = non-coupled structure (given for comparison)
Note: laboratory measurement

(2002 Hongisto V. et. al)
Double structures
Double masonry structure

Structure 1:
- Rendered brick 110 mm
- Airspace + mineral wool 50 mm
- Rendered brick 110 mm

Structure 2:
- Rendered brick 220 mm
- Airspace + mineral wool 230 mm
- Rendered brick 220 mm
Double vs. single structure

**Structure 1:**
- concrete 180 mm

**Structure 2:**
- 2 x gypsum board 13 mm
- mineral wool 150 mm
- 2 x gypsum board 13 mm

Due to mass-air-mass resonance, sound insulation of a double-leaf partition is weaker at low frequencies than a single masonry structure.

This phenomenon is the cause for, e.g., complaints about poor sound insulation between up- and downstairs in row houses!
Triple structure

• The differences in sound insulation between triple and double partitions has been investigated, e.g., by Uris et al. 2003

• It was found that the sound reduction index $R_w$ of a triple structure is up to 7-8 dB less than that of a double structure with similar mass and thickness

• The deterioration in sound insulation occurs at low frequencies ($\leq 170$ Hz in the investigation) and is caused by the extraneous mass-air-mass resonance caused by the third plate layer

Triple structure

Avoid triple structures!
Lightweight sandwich structures

• In a lightweight sandwich structure plates are coupled to each other with a flexible and light core material, which is are glued to the plates (pintalevyt kytketty toisiinsa joustavalla ja kevyellä ydinaineella)
Lightweight sandwich structure
Dilatation resonance

• The most important phenomenon deteriorating sound insulation: *dilatation resonance (dilataatioresonanssi)*

\[ f_d = \frac{1}{2\pi} \sqrt{\frac{s'}{m_1 + m_2}} \]

• where \( s' \) is the dynamic stiffness of the core material (MN/m3) and \( m_1, m_2 \) are the surface masses of the plates
  – Corresponds to the mass-air-mass resonance of a double-leaf partition...
  – ...but: is at a higher frequency than \( f_{\text{mam}} \), because the dynamic stiffness of the core material is significantly higher than that of air with same thickness
  – Dilatation resonance usually between 500...2000 Hz
  \[ \rightarrow \] Significantly diminishes the \( R_w \) value!
Lightweight sandwich structure

Effect of core material thickness

Plates: 1.0 mm steel, core material mineral wool (100 kg/m³)

Plates: 0.6 mm steel, core material wool (125 kg/m³)

In the left figure the dynamic stiffness of mineral wool is significantly higher than in the right figure → dilation resonance at a lower frequency.
Lightweight sandwich structure
Effect of core material fiber direction

Dynamic stiffness of mineral wool is higher in the direction of fibers (poikkivilla) than perpendicular to fibers (lomavilla).
### Sound insulation of sandwich structures

<table>
<thead>
<tr>
<th>Concrete inner envelope [mm]</th>
<th>Insulation material</th>
<th>Concrete exterior envelope [mm]</th>
<th>$R_w(C, C_{tr})$ [dB]</th>
</tr>
</thead>
<tbody>
<tr>
<td>80 mm</td>
<td>160 mm eriste</td>
<td>70 mm</td>
<td>54 (-1,-4) dB</td>
</tr>
<tr>
<td>150 mm</td>
<td>160 mm eriste</td>
<td>70 mm</td>
<td>60 (-1,-4) dB</td>
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<tr>
<td>80 mm</td>
<td>250 mm eriste</td>
<td>70 mm</td>
<td>54 (-1,-4) dB</td>
</tr>
<tr>
<td>150 mm</td>
<td>250 mm eriste</td>
<td>70 mm</td>
<td>60 (-1,-4) dB</td>
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<tr>
<td>80 mm</td>
<td>450 mm eriste</td>
<td>70 mm</td>
<td>54 (-0,-3) dB</td>
</tr>
<tr>
<td>150 mm</td>
<td>450 mm eriste</td>
<td>70 mm</td>
<td>60 (-1,-4) dB</td>
</tr>
</tbody>
</table>
## Sound insulation of structures with concrete inner envelope and rendered insulation

<table>
<thead>
<tr>
<th>Betonien sisäkuori [mm]</th>
<th>eriste paksuus + tyyppi</th>
<th>Rappaus [mm]</th>
<th>$R_w$ (C, $C_{ir}$) [dB]</th>
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<tbody>
<tr>
<td>150 mm</td>
<td>160 mm EPS</td>
<td>10 mm</td>
<td>52 (-3,-7) dB</td>
</tr>
<tr>
<td>150 mm</td>
<td>160 mm EPS</td>
<td>25 mm</td>
<td>54 (-4,-9) dB</td>
</tr>
<tr>
<td>150 mm</td>
<td>160 mm FAL1</td>
<td>10 mm</td>
<td>53 (-2,-5) dB</td>
</tr>
<tr>
<td>150 mm</td>
<td>160 mm FAS4</td>
<td>25 mm</td>
<td>56 (0,-4) dB</td>
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<td>150 mm</td>
<td>250 mm EPS</td>
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<td>250 mm FAS4</td>
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<td>58 (-1,-5) dB</td>
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<td>150 mm</td>
<td>450 mm FAS4</td>
<td>25 mm</td>
<td>59 (-1,-4) dB</td>
</tr>
</tbody>
</table>
Sound insulation of doors
Single door

Diagram showing the sound insulation of doors at different frequencies and conditions. The graph plots the sound absorption coefficient $R$ in dB against frequency in Hz. Different lines represent various configurations:
- Ei tiivisteitä, ei kynnystä, ei peitelistaa (24 dB)
- Ei kynnystä, lisälista (29 dB)
- Kynys, yhden tiivisteet (43 dB)
- Kynys, tupla-tiivisteet (43 dB)
- Kynys, tupla-tiivisteet, teipattu (46 dB)
Sound insulation of doors
Double door

Ilmaääneneristävyys [dB]

Yksittäinen ovi, 37 dB
Kaksi ovea, 35 mm ilmarako, 44 dB
Kaksi ovea, 65 mm ilmarako, 48 dB
Kaksi ovea, 115 mm ilmarako, 49 dB


Ovet oli asennettu normaalisti. Teipattujen ovien \( R_w \)-arvot olivat 2, 4, 1 ja 1 dB korkeampia.
Sound insulation of glass

- Graphs showing sound insulation of glass at different frequencies for 3 mm, 6 mm, and 12 mm thicknesses.
- Graphs for 4/(6-16)/4, 8/(6-16)/4, and 10/(6-16)/6 thicknesses as well.
### Sound insulation of glass

<table>
<thead>
<tr>
<th></th>
<th>125</th>
<th>250</th>
<th>500</th>
<th>1000</th>
<th>2000</th>
<th>4000</th>
<th>$R_w$</th>
<th>$C$</th>
<th>$C_{tr}$</th>
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</table>
Combined sound insulation

- The combined sound insulation (yhteisääneneristävyys) of a structure comprising of several elements can be calculated when sound power is assumed to be distributed on the structural elements \( i \) in proportion to their area \( S_i \).

- Combined sound insulation using the SRIs \( R_i \) of elements \( i \):

\[
R = 10 \log \left( \frac{\sum_{i=1}^{n} S_i}{\sum_{i=1}^{n} S_i 10^{-R_i/10}} \right)
\]

(ta)

\[
R_w = 10 \log \left( \frac{\sum_{i=1}^{n} S_i}{\sum_{i=1}^{n} S_i 10^{-R_{w,i}/10}} \right)
\]

(calculation in frequency bands)

(calculation using weighted sound reduction indices)
Combined sound insulation

Combined sound insulation of structures 1 and 2

$R_{w,1} = 60 \, \text{dB}$

$R_{w,2}$ changes

Percentage (%) of the area of structure 2 to total area

Aalto-yliopisto
Teknillinen korkeakoulu
Effect of holes on sound insulation

Combined sound insulation of hole and solid structure

Percentage (%) of the hole area to the area of the solid structure

Ra on ja rakenteen yhteiseristävyys, $R_{yhteis}$ [dB]

Percentage (%) of the hole area to the area of the solid structure

Ra osuus väliseinän pinta-alasta [%]
Effect of holes on sound insulation

• The effect of holes is largest when the SRI of the solid structure is high.

• If total area of a structure is $S_1$ and SRI $R_1$ and correspondingly $S_2$ and $R_2$ for the hole, combined sound insulation can be calculated from the equation:

$$ R_{\text{yhteis}} = 10 \log_{10} \frac{S_1 + S_2}{S_1 \cdot 10^{-R_1/10} + S_2 \cdot 10^{-R_2/10}} $$

• The SRI of a hole with hard surfaces can be assumed to be (simplified) $R_2 = 0$ dB, more accurately SRI of a hole is frequency dependent.
Effect of holes on sound insulation
Example: door lock prior to and after sealing
Effect of absorption on sound insulation

![Graph showing the effect of absorption on sound insulation. The graph plots the sound absorption coefficient against frequency (Hz). The graph includes two lines, one for a single plasterboard (31 dB) and another for a plasterboard with 50 mm of mineral wool (37 dB). The graph also includes a dashed line indicating an improvement in sound absorption.]
Effect of plate perforation on sound insulation

[Remes 2009]
Flanking transmission
Flanking transmission
Transmission paths in a building
Flanking transmission
Phenomenon and meaning

- Laboratory measurement yields the sound reduction index of a single building element (partition etc.)
- In a building sound is transmitted between spaces not only directly through the separating structure, but via flanking structures as flaking transmission
- This phenomenon is called structural flanking transmission
- The greater the sound insulation requirement between spaces, the more effect flanking has on sound insulation and the more the design of sound insulation becomes minimizing of flanking transmission
Flanking transmission
Structural flanking transmission

• Calculation model presented in standard EN 12354-1
• Can be used for calculations sound reduction index when flanking structures are massive masonry structures (e.g. Concrete wall) or when a lightweight structure connects to a massive structure
• The model does not give reliable results if the flanking structures are lightweight!
Flanking transmission
Structural flanking transmission – calculation model

• Notation of flanking paths according to EN 12354-1:
Flanking transmission
Structural flanking transmission – calculation model

- In order to calculate the $R_{\text{w}}$ in a building, the sound reduction index along each flanking path need to be known
- Number of direct sound paths: 1 (Dd)
- Number of flanking sound paths: $4 \times F_f, 4 \times D_f, 4 \times F_d = 12$
- These are first-order flanking paths, meaning that sound traverses to the receiving room over one structural junction only
- Sound also traverses along 2., 3. order etc. Flanking paths; these need not however be considered, because omitting the higher order flanking paths from the calculation underestimates the flanking sound energy by only about 1 dB
Flanking transmission
Structural flanking transmission – calculation model

• Most significant factor affecting flanking transmission is the type of the junction along the flanking path
• **Vibration reduction index** of the junction (värähtely- tai liitoseristävyys) $K_{ij} \ [dB]$ describes the vibration isolation capacity of the junction in decibels
• Vibration reduction is affected by the amount of structures involved and their surface masses
• Vibration reduction improves when the amount of structures involved in the junction increases (+ junction is better than T-junction) and when the difference in surface masses of the structures increases
Flanking transmission
Structural flanking transmission – calculation model

- SRI of direct path:
  \[ R_{Dd,w} = R_{s,w} + \Delta R_{Dd,w} \]
  where \( R_{s,w} \) is the SRI of separating massive (masonry) wall and \( \Delta R_{Dd,w} \) is the improvement to SRI caused by lightweight cladding in source or receiving room.

- In the case of only a massive separating structure without cladding \( \Delta R_{Dd,w} = 0 \), the equation simplifies to:
  \[ R_{Dd,w} = R_{s,w} \]
Flanking transmission
Structural flanking transmission – calculation model

- The sound reduction indexes corresponding to three flanking paths Ff, Fd, Df:
  - Via flanking structure:
    \[
    R_{Ff,w} = \frac{R_{F,w} + R_{f,w}}{2} + \Delta R_{Ff,w} + K_{Ff} + 10 \log \frac{S_s}{l_f}
    \]
  - Via flanking and separating structure:
    \[
    R_{Fd,w} = \frac{R_{F,w} + R_{s,w}}{2} + \Delta R_{Fd,w} + K_{Fd} + 10 \log \frac{S_s}{l_f}
    \]
  - Via separating and flanking structure:
    \[
    R_{Df,w} = \frac{R_{s,w} + R_{f,w}}{2} + \Delta R_{Df,w} + K_{Df} + 10 \log \frac{S_s}{l_f}
    \]

- Flanking transmission
Structural flanking transmission – calculation model
Flanking transmission
Structural flanking transmission – calculation model

- $R_w'$ corresponding to SRI measured in the field is calculated from equation:

$$R_w' = -10 \log \left( 10^{-R_{Dd,w}/10} + \sum_{F=f=1}^{4} 10^{-R_{Ff,w}/10} + \sum_{F=1}^{4} 10^{-R_{Fd,w}/10} + \sum_{f=1}^{4} 10^{-R_{Df,w}/10} \right)$$

- If the separating partition is lightweight, terms $Df$ and $Fd$ can be omitted (because vibration isolation in the junction of lightweight and massive structure is large) and only calculate patha Dd and Ff

- If flanking structures are lightweight, the model does not give reliable results
Flanking transmission
Vibration reduction of stiff joints

Cross junction: 9 dB
T-junction: 6 dB
Flanking transmission
Vibration reduction of flexible joints

- Vibration reduction in a flexible junction is even 10 dB higher than in a rigid junction.

- Note: Flexible junction is only useful if sound traverses along the junction! (no vibration reduction along path $K_{24}$)
Flanking transmission
Joints between lightw. and heavy structure

• The difference in surface masses is high compared to the situation with two intersecting massive structures
  – In the junction of massive structures \( m_2/m_1 \approx 1 \), whereas in the junction of massive and lightweight structure it is \( m_2/m_1 > 10 \) or even \( m_2/m_1 > 30 \)
  \( \rightarrow \) vibration reduction indexes are significantly higher than in the junction of massive structures...

• ... On the other hand when sound traverses along the massive structure pass the junction of a lightweight structure vibration reduction index is poor
Flanking transmission
Joints between lightw. and heavy structure
Flanking transmission
Joints between lightw. and heavy structure
Flanking transmission
Joints between lightw. and heavy structure

• The sound reduction index of one half of a double-leaf partition is quite low (single building board, Rw typically 25...30 dB)

• If a double-leaf partition separating two rooms connects to a massive structure, flanking can occur because of the poor sound insulation of the partition half (although the vibration reduction index of the junction is high)

• Because of this, lightweight flanking structures usually need to truncated at the separating wall junction
  – Lightweight partitions
  – Thin lightweight masonry structures (e.g. lightweight concrete, a layer of render on brick wall)
Flanking transmission
Example: lightweight partition – flanking wall

Requirement between spaces:
$R_w \geq 55$ dB

[Remes 2009]
Flanking transmission
Example: lightweight partition – flanking wall

Requirement between spaces: $R_w' \geq 45$ dB

[Remes 2009]
Flanking transmission
Example: lightweight partition – flanking wall

Requirement between spaces: $R_w \geq 35$ dB

[Remes 2009]
Flanking transmission
Example: truncation of floating floor slab

- Requirement between spaces: $R'_{w} \geq 60$ dB
- Floating floor concrete slab (60 mm) was built so that it extended continuously from room to room, measurement result: $R'_{w} = 52$ dB
- Result after truncation of the slab: $R'_{w} = 62$ dB
- Note: critical frequency of 60 mm concrete slab is about 370 Hz

[Kylliäinen 2007]
Flanking transmission
Example: connection between partition/facade

- Wall separating rooms:
  - Gypsum board partition, $R_w = 62$ dB
- Inner concrete envelope of exterior wall
  - Concrete 80 mm, $R_w = 48$ dB
  - Concrete 150 mm, $R_w = 57$ dB

- Other structures
  - Floor: concrete slab 240 mm, $R_w = 64$ dB
  - Flanking concrete wall 180 mm, $R_w = 60$ dB
Flanking transmission
Example: connection between partition/facade

- Wall separating rooms:
  - Concrete 180 mm, $R_w = 60$ dB
- Inner concrete envelope of exterior wall
  - Concrete 80 mm, $R_w = 48$ dB
  - Concrete 150 mm, $R_w = 57$ dB

- Other structures
  - Floor: concrete slab 240 mm, $R_w = 64$ dB
  - Flanking concrete wall 180 mm, $R_w = 60$ dB
Flanking transmission
Example: row house, partition/exterior wall

Tuulensuojalevyä tukevat rimat katkaistaan

Tiivistys elastisella kitillä

Seinäelementti 180 mm
Flanking transmission
Lightweight structures

Diminishing flanking transmission in the connection between two double-leaf partitions
Flanking transmission
Lightweight structures

Wooden apartment building, junction between floor and partition separating dwellings

Junction of lightweight partition separating dwellings to exterior wall

[Kylliäinen 2007]