ACOUSTIC DESIGN

ERIK IPSEN
Head of Research & Design

DANOLINE
BACKGROUND

- Architect, M.A.A. (Member of the Danish Architect Association)
- Member of the Danish Acoustic Standardization Board
- Member of the Swedish Acoustic Standardization Board
- Member of the European Acoustic Standardization Board

- 20 years of experience with acoustical development
- Own testing facilities:
  - Sound absorption
  - Sound reduction
  - Sound diffusion
KNAUF DANOLINE
PERFORATED BOARDS
CLADDINGS
SUSPENDED CEILINGS
SELF SUPPORTING CEILINGS
CURVES
MITRED BOARDS
STRUCTURES
GOAL

SOUND CONTROL THOUGH ARCHITECTURE AND INTERIOR DESIGN
AGENDA

• SOUND
• REVERBERATION TIME
• SOUND CONTROLLING TOOLS
• SOLUTIONS SCHOOLS
SOUND
THE FIRST | THE LAST
MOVEMENT OF SOUND
SOUND or NOISE
PERCEPTION OF SOUND
PERCEPTION OF SOUND

?
SOUND LEVEL
PURPOSE OF THE ACOUSTICS
REVERBERATION TIME
ROOMS FOR WORK
ROOMS FOR SPEECH
REV. TIME: CLASSROOMS

Efterklangstid, $T_e$:

- Klasseområde
- Undervisningsområde til sløjde
- Undervisningsområde til sang og musik mindre end 250 m$^3$ (korsang og akustisk musik) $\leq 1.1$ s
- Undervisningsområde til sang og musik mindre end 250 m$^3$ (elektrisk forstærket) $\leq 0.6$ s
- Gymnastiksali mindre end 3500 m$^3$ $\leq 1.6$ s
- Gymnastiksali større end 3500 m$^3$ $\leq 1.8$ s
- Svømmehaller mindre end 1500 m$^3$ $\leq 2.0$ s
- Svømmehaller større end 1500 m$^3$ $\leq 2.3$ s
- Fællesrum samt fællesgange, der benyttes til gruppearbejde og lignende $\leq 0.4$ s
- Fællesgange, der ikke benyttes til gruppearbejde og lignende $\leq 0.9$ s
- Trapperom $\leq 1.3$ s

Absorptionsareal, $A_e$:

- Abne undervisningsområder $\geq 1.3 \times$ gulvareal
- Fællesrum med oftehøjere større end 4 m og rumvolumen større end 300 m$^3$ $> 1.2 \times$ gulvareal
REVERBERATION TIME

- Ultrashort RT 0.2-0.4 s
- Short RT 0.4-0.6 s
- Normal RT 0.6-0.8 s
- Long RT 0.8-1.5 s
EDUCATION ROOM

CLASSROOM 0.6 sec. (min. 0.4 sec.)
HIGHER ABSORPTION IN CEILING
CAUTION !!!

- DRY ACOUSTICS
- LARGE, PLAIN WALL SURFACES (USE OF WALL ABSORBERS)
- RISK OF GEOMETRIC REFLECTIONS
- LACK OF SOUND ABSORBING MATERIALS
- IRREGULAR ABSORPTION PROFILE
- LARGE CEILING HEIGHTS
- INCLINED CEILING AREAS WITHOUT ABSORBERS
- DOUBLE STOREY ROOMS WITH BALCONIES (MEZZANINE DECK)
- CURVED SURFACES
- PARALLEL HARD SURFACES
- CIRCULAR ROOM DESIGNS
- LACK OF DIFFUSION
- ROOM DIMENSIONS 2:1
- LARGE GLASS SURFACES
- FLOOR COVERINGS WITH DRUMMING SOUND
CLOSED ROOM
REVERBERATION TIME
REVERBERATION TIME
PLAIN TILES

KINOPANEL
ECHO

50 ms = 17 m / 2 = 8.5
REV. TIME – BEFORE AND AFTER

<table>
<thead>
<tr>
<th></th>
<th>125</th>
<th>250</th>
<th>500</th>
<th>1000</th>
<th>2000</th>
<th>4000</th>
</tr>
</thead>
<tbody>
<tr>
<td>EMPTY ROOM</td>
<td>1.12</td>
<td>1.25</td>
<td>2.02</td>
<td>1.84</td>
<td>1.71</td>
<td>1.52</td>
</tr>
<tr>
<td>DIFFUSERS</td>
<td>0.72</td>
<td>0.65</td>
<td>0.70</td>
<td>0.72</td>
<td>0.69</td>
<td>0.70</td>
</tr>
<tr>
<td>FURNITURE</td>
<td>0.69</td>
<td>0.59</td>
<td>0.61</td>
<td>0.58</td>
<td>0.57</td>
<td>0.59</td>
</tr>
</tbody>
</table>
DIFFUSION / ABSORPTION
SUM UP

• EFFICIENT ABSORBERS IN CEILING GIVES RISK OF ECHOS.

• LACK OF DIFFUSION GIVES VERY LOW EFFECT OF ABSORBERS
SOUND CONTROLLING TOOLS
MATERIALS
ABSORBERS
ABSORBERS

• Visual skin
• Design
• Absorbs sound
• Diffuse sounds
• Reflect sounds
• Part of the indoor climate
• Reflects light
• Stability
• Breathes
• Fire security
ADIT – WALL LINING
SPREADING OF SOUND
SOUND WAVE LENGTH

\[
\begin{align*}
125\text{Hz (50/60Hz)} & \\
\frac{340\text{m/s}}{125} & = 2.72\text{m}
\end{align*}
\]

\[
\begin{align*}
4000\text{Hz} & \\
\frac{340\text{m/s}}{4000} & = 0.085\text{m}
\end{align*}
\]
REFLECTION
ACOUSTIC MATERIALS

- FIBROUS ABSORBERS
- PERFORATED ABSORBERS
- PERFORATED ABSORBERS WITH ACOUSTIC BACKING
- DIFFUSERS
- MEMBRANES
- SLIT ABSORBERS
REFLECTION
MEMBRANE ABSORPTION
RESONANCE ABSORPTION
RESONANCE ABSORPTION
DIFFUSION
PERFORATED BOARDS
EFFECTS OF PERFORATED TILES

SOUND REGULATING EFFECT

ACOUSTIC BALANCE
LABORATORY MEASUREMENT OF SOUND ABSORPTION COEFFICIENT
ACCORDING TO EN ISO 354:2003

Client: Danoline A/S, Kløvermarkvej 4, 9500 Hobro
Date of test: 10 January 2007

Test specimen: Danoline Contour 600 Tangram TI, Perforation 21.5%
Thickness: 13 mm
Module size: 480 mm x 600 mm
Mounting depth: 200 mm (Type E-200 mounting)

Test area: 10.8 m²
Room volume: 21.5 m³
Room surface: 305 m²

<table>
<thead>
<tr>
<th>Frequency (Hz)</th>
<th>0.25</th>
<th>0.50</th>
<th>1.00</th>
<th>2.00</th>
<th>4.00</th>
<th>8.00</th>
<th>12.50</th>
</tr>
</thead>
<tbody>
<tr>
<td>125</td>
<td>0.65</td>
<td>0.70</td>
<td>0.75</td>
<td>0.80</td>
<td>0.85</td>
<td>0.90</td>
<td>0.95</td>
</tr>
<tr>
<td>250</td>
<td>0.60</td>
<td>0.65</td>
<td>0.70</td>
<td>0.75</td>
<td>0.80</td>
<td>0.85</td>
<td>0.90</td>
</tr>
<tr>
<td>500</td>
<td>0.50</td>
<td>0.55</td>
<td>0.60</td>
<td>0.65</td>
<td>0.70</td>
<td>0.75</td>
<td>0.80</td>
</tr>
<tr>
<td>1000</td>
<td>0.45</td>
<td>0.50</td>
<td>0.55</td>
<td>0.60</td>
<td>0.65</td>
<td>0.70</td>
<td>0.75</td>
</tr>
<tr>
<td>2000</td>
<td>0.40</td>
<td>0.45</td>
<td>0.50</td>
<td>0.55</td>
<td>0.60</td>
<td>0.65</td>
<td>0.70</td>
</tr>
<tr>
<td>4000</td>
<td>0.35</td>
<td>0.40</td>
<td>0.45</td>
<td>0.50</td>
<td>0.55</td>
<td>0.60</td>
<td>0.65</td>
</tr>
</tbody>
</table>

Practical sound absorption coefficient, weighted sound absorption coefficient, and absorption class according to EN ISO 11654:1997.

Absorption class: C

SPEECH CONTROL

NOISE CONTROL
SUM UP

- PRODUCT ABSORPTION PROFILE CAN BE DESIGNED.

- ABSORPTION VALUES FOR SPEECH CONTROL UNDER 0,70 aw

- ABSORPTION PROFILE FOR NOISE REDUCTION OVER 0,70 aw
SOUND CONTROLLING TOOLS
POSITIONING OF ABSORBERS
ACOUSTIC DESIGN & ARCHITECTURE
NORMAL CEILING HEIGHT
NARROW ROOM
LARGE CEILING HEIGHT
# AMOUNT OF ABSORBERS

<table>
<thead>
<tr>
<th>% of floor area</th>
<th>Absorption Material Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.5 – 2.8 m</td>
<td>100% absorption materials on ceilings</td>
</tr>
<tr>
<td>2.8 – 3.2 m</td>
<td>115% absorption materials = (100% on ceiling + 15% on walls)</td>
</tr>
<tr>
<td>3.2 – 3.8 m</td>
<td>120% absorption materials</td>
</tr>
<tr>
<td>3.8 – 4.0 m</td>
<td>125% absorption materials</td>
</tr>
<tr>
<td>above 4.0 m</td>
<td>No recommendation</td>
</tr>
</tbody>
</table>
SUM UP

• CEILING HIGH OVER 2,6 m SHOULD BE ADDED WITH WALL ABSORBERS.

• WORKPLACES WITH A CEILING HIGH OVER 4m IS NOT RECOMMENDED.
SOUND CONTROLLING TOOLS
GEOMETRIC SOUND REGULATION
INCLINED CEILINGS
MEZZANINE
CURVED SURFACES
INCLINED WALLS
ROUND ROOMS
STRUCTURED CEILINGS
SUM UP

• SOUND REGULATING MATERIALS SHOULD BE PLACED WHERE THE SOUNDWAVES HIT FIRST.

• STRUCTURES MIRRORS THE SOUNDWAVES / THINK ABOUT THE FORM OF THE STRUCTURE AND HOW IT REFLECTS SOUNDS.
SOUND CONTROLLING TOOLS
FURNITURE
FURNITURE
DIFFERENT CEILING TYPES

- NO WALL ABSORBERS
- NO FURNITURE
CEILING TYPES

DIFFERENT CEILING TYPES  NO WALL LININGS  NO FURNITURE
FURNITURE

- DIFFERENT CEILING TYPES
- NO WALL LININGS
- MODERATE FURNISHING
FURNITURE

| DIFFERENT CEILING TYPES | NO WALL LININGS | MODERATE FURNISHING |
FURNITURE AND WALL LININGS

- DIFFERENT CEILING TYPES
- WALL LININGS
- MODERATE FURNISHING
FURNITURE AND WALL LININGS

| DIFFERENT CEILING TYPES | WALL LININGS | MODERATE FURNISHING |
# FURNITURE DIFFUSION FACTOR

<table>
<thead>
<tr>
<th></th>
<th>FLOOR SURFACE x $\alpha w$</th>
</tr>
</thead>
<tbody>
<tr>
<td>DENSLY FURNISHED</td>
<td>$0.30$</td>
</tr>
<tr>
<td>MODERATELY FURNISHED</td>
<td>$0.20$</td>
</tr>
<tr>
<td>SPARSELY FURNISHED</td>
<td>$0.15$</td>
</tr>
<tr>
<td>UNFURNISHED</td>
<td>$0$</td>
</tr>
</tbody>
</table>
FURNITURE
SUM UP

• FURNITURE HAS A MAJOR INFLUENCE OF SOUND DIFFUSION / AND THE EFFECT OF HOW EFFICIENT A ABSORBER IS PERFORMING.

• THE EFFECT IS VERY IMPORTANT IN LARGE ROOM OFFICES.
SOLUTIONS

SCHOOLES
IMPORTANT FREQUENCIES

• CONSONANTS
• 250 - 3150 Hz
• The most important frequency - 500 Hz
FREQUENCIES

20 - 20,000 Hz

audio cond
10 year
30 year
50 year.
ROOMS FOR SPEECH
ROOMS FOR SPEECH
CEILING HEIGH

100%

15%

3 m
ECHO

8.5 m

50 ms = 17 m / 2 = 8.5
DIMENSION

Dimension not bigger than 2 to 1

75 m²
BULK HEADS - DELAYED ECHOS

GOOD DIFFUSION

RISK OF DELAYED ECHO
ABSORPTION PROFILE under 0.70 aw

Laboratory Measurement of Sound Absorption Coefficient according to EN ISO 354:2003

<table>
<thead>
<tr>
<th>Frequency (Hz)</th>
<th>%</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>125</td>
<td>0.10</td>
<td></td>
</tr>
<tr>
<td>500</td>
<td>0.22</td>
<td></td>
</tr>
<tr>
<td>1000</td>
<td>0.67</td>
<td></td>
</tr>
<tr>
<td>2000</td>
<td>0.60</td>
<td></td>
</tr>
<tr>
<td>4000</td>
<td>0.25</td>
<td></td>
</tr>
</tbody>
</table>

Absorption class: C

\[ \alpha_r = 0.05 \]
LEVELED REVERBERATION TIME

CLASSROOM 0.6 sec. (min. 0.4 sec.)
# CALCULATION OF REVERBERATION TIME

<table>
<thead>
<tr>
<th>Placing of Face:</th>
<th>Area:</th>
<th>Description</th>
<th>125 Hz</th>
<th>250 Hz</th>
<th>500 Hz</th>
<th>1000 Hz</th>
<th>2000 Hz</th>
<th>4000 Hz</th>
</tr>
</thead>
<tbody>
<tr>
<td>2C</td>
<td>34.0</td>
<td>Brick wall 1 glazed window</td>
<td>0.13</td>
<td>2.40</td>
<td>3.07</td>
<td>1.88</td>
<td>0.35</td>
<td>1.23</td>
</tr>
<tr>
<td>22</td>
<td>3L</td>
<td>Jl</td>
<td>0.23</td>
<td>0.11</td>
<td>0.22</td>
<td>0.60</td>
<td>1.15</td>
<td>1.21</td>
</tr>
<tr>
<td>22</td>
<td>7C, 0</td>
<td>Faux plume on concrete</td>
<td>0.02</td>
<td>0.02</td>
<td>0.02</td>
<td>0.10</td>
<td>0.33</td>
<td>2.13</td>
</tr>
<tr>
<td>1F</td>
<td>7F, 0</td>
<td>Faux 12-22 mm and 4 mm wall</td>
<td>0.16</td>
<td>1.87</td>
<td>1.67</td>
<td>7.60</td>
<td>1.16</td>
<td>4.81</td>
</tr>
<tr>
<td>44</td>
<td>7C, 0</td>
<td>Plinum milled</td>
<td>0.16</td>
<td>0.60</td>
<td>1.16</td>
<td>17.50</td>
<td>1.16</td>
<td>1.51</td>
</tr>
<tr>
<td>121</td>
<td>7C, 0</td>
<td>Conc. 300 m/1 suspended 200-30</td>
<td>0.42</td>
<td>20.07</td>
<td>3.55</td>
<td>33.50</td>
<td>0.55</td>
<td>4.33</td>
</tr>
</tbody>
</table>

**Reverb. Time**

Wished reverberation time

---

**Graph:**

- **Y-axis:** Seconds
- **X-axis:** Reverb. time

---

**Note:**

- The table and graph illustrate the calculation of reverberation time, showing the absorption properties of different materials in various frequencies (125 Hz, 250 Hz, 500 Hz, 1000 Hz, 2000 Hz, 4000 Hz) and their impact on reverberation times.

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**Legend:**

- 2C: Brick wall 1 glazed window
- 22: Jl
- 22: Faux plume on concrete
- 1F: Faux 12-22 mm and 4 mm wall
- 44: Plinum milled
- 121: Conc. 300 m/1 suspended 200-30
GLASS FACADES
GLASS FACADES
MEZZANINE
DRUM SOUND
SUM UP

• EFFICIENT ABSORBERS IN CEILING GIVES RISK OF ECHOS.

• LACK OF DIFFUSION GIVES VERY LOW EFFECT OF ABSORBERS
SUM UP

• PRODUCT ABSORPTION PROFILE CAN BE DESIGNED.

• ABSORPTION VALUES FOR SPEECH CONTROL UNDER 0,70 aw

• ABSORPTION PROFILE FOR NOISE REDUCTION OVER 0,70 aw
SUM UP

• CEILING HIGH OVER 2,6 m SHOULD BE ADDED WITH WALL ABSORBERS.

• WORKPLACES WITH A CEILING HIGH OVER 4m IS NOT RECOMMENDED.
SUM UP

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• STRUCTURES MIRRORS THE SOUNDWAVES / THINK ABOUT THE FORM OF THE STRUCTURE AND HOW IT REFLECTS SOUNDS.
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• FURNITURE HAS A MAJOR INFLUENCE OF SOUND DIFFUSION / AND THE EFFECT OF HOW EFFICIENT A ABSORBER IS PERFORMING.

• THE EFFECT IS VERY IMPORTANT IN LARGE ROOM OFFICES.
GOAL

SOUND CONTROL THOUGH ARCHITECTURE AND INTERIOR DESIGN
ACOUSTIC DESIGN BOOKS
Measurements on site
perforated gypsum or mineral wool

<table>
<thead>
<tr>
<th>Room</th>
<th>125 Hz</th>
<th>250 Hz</th>
<th>500 Hz</th>
<th>1000 Hz</th>
<th>2000 Hz</th>
<th>4000 Hz</th>
<th>Average / Highest *)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Room A</td>
<td>0.6</td>
<td>0.6</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5 / 0.6</td>
</tr>
<tr>
<td>(C absorber)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Room B</td>
<td>0.6</td>
<td>0.6</td>
<td>0.5</td>
<td>0.4</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5 / 0.6</td>
</tr>
<tr>
<td>(A absorber)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
ASTM

<table>
<thead>
<tr>
<th>NRC (NOISE REDUCTION COEFFICIENT)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AVERAGE 250 – 2000 Hz</td>
</tr>
<tr>
<td>400mm SUSPENSION</td>
</tr>
<tr>
<td>EN STANDARDS: 200mm SUSPENSION</td>
</tr>
</tbody>
</table>
ASTM - NRC

Test area: 10.8 m²
Room volume: 210 m³
Room surface: 305 m²

<table>
<thead>
<tr>
<th>Frequency f [Hz]</th>
<th>α₀</th>
</tr>
</thead>
<tbody>
<tr>
<td>125</td>
<td>0.45</td>
</tr>
<tr>
<td>250</td>
<td>0.60</td>
</tr>
<tr>
<td>500</td>
<td>0.75</td>
</tr>
<tr>
<td>1000</td>
<td>0.65</td>
</tr>
<tr>
<td>2000</td>
<td>0.65</td>
</tr>
<tr>
<td>4000</td>
<td>0.60</td>
</tr>
</tbody>
</table>

Practical sound absorption coefficient

Frequency, f [Hz]
250 – 2000 Hz

- Test area: 10.8 m²
- Room volume: 210 m³
- Room surface: 305 m²

<table>
<thead>
<tr>
<th>Frequency f [Hz]</th>
<th>$\alpha_p$</th>
</tr>
</thead>
<tbody>
<tr>
<td>125</td>
<td>0.45</td>
</tr>
<tr>
<td>250</td>
<td>0.60</td>
</tr>
<tr>
<td>500</td>
<td>0.75</td>
</tr>
<tr>
<td>1000</td>
<td>0.65</td>
</tr>
<tr>
<td>2000</td>
<td>0.65</td>
</tr>
<tr>
<td>4000</td>
<td>0.60</td>
</tr>
</tbody>
</table>
AVERAGE

Test area: 10.8 m²
Room volume: 210 m³
Room surface: 305 m²

<table>
<thead>
<tr>
<th>Frequency f [Hz]</th>
<th>$a_0$</th>
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</thead>
<tbody>
<tr>
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<td>0.45</td>
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<tr>
<td>250</td>
<td>0.60</td>
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<tr>
<td>500</td>
<td>0.75</td>
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<tr>
<td>1000</td>
<td>0.65</td>
</tr>
<tr>
<td>2000</td>
<td>0.65</td>
</tr>
<tr>
<td>4000</td>
<td>0.60</td>
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</tbody>
</table>

Practical sound absorption coefficient

Frequency, f [Hz]
NRC VALUE

Test area: 10.8 m²
Room volume: 210 m³
Room surface: 305 m²

<table>
<thead>
<tr>
<th>Frequency f [Hz]</th>
<th>$\alpha_p$</th>
</tr>
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<tbody>
<tr>
<td>125</td>
<td>0.45</td>
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<tr>
<td>250</td>
<td>0.60</td>
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<tr>
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<tr>
<td>2000</td>
<td>0.65</td>
</tr>
<tr>
<td>4000</td>
<td>0.60</td>
</tr>
</tbody>
</table>

Practical sound absorption coefficient

Frequency, f [Hz] vs. Practical sound absorption coefficient

NRC = 0.65
ASTM

| NRC (NOISE REDUCTION COEFFICIENT) |
| AVERAGE 250 – 2000 Hz |

![Graph showing NRC (Noise Reduction Coefficient) for 250 to 2000 Hz range with a peak at NRC 0.75 at 1000 Hz.](image)
Sound Lab

2.34 m
2.24 m
11.25 m

Speaker

Microphone
Sound Lab
Short Reverberation time

50 ms = 17 m / 2 = 8.5 + 8.5
Flutter Plain Tiles

File: C:\MLSSA\DAN049.TIM 4-1-108 12:06 PM
Impulse Response - volts

Comment: Afstand til vlg2.76 plade plade.
Flutter Kinopanel

File: C:\MLSSA\DA07E.TIM 4-1-106 2:08 PM

Impulse Response - Volts

Comment: kino kino, dug +45 afst. 2.75 fra veg
Plain Tiles

Kinopanel
### dB Loss

<table>
<thead>
<tr>
<th></th>
<th>125</th>
<th>250</th>
<th>500</th>
<th>1 kH</th>
<th>2 kH</th>
<th>4 kH</th>
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<tbody>
<tr>
<td><strong>Plain</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-11,5</td>
<td>-11,8</td>
<td>-1,8</td>
<td>4,9</td>
<td>15,8</td>
<td>10,7</td>
<td></td>
</tr>
<tr>
<td>-12</td>
<td>-17</td>
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Influence of friezes

Unfurnished classroom with perforated gypsum ceiling; no wall absorbers