Listening tests in building acoustics

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Introduction

The visual dominance in “Western life”
✧ architecture, new technology (touchscreens ...)

Description of acoustic comfort
✧ numbers, graphs and pictures, visualization of acoustic phenomena
✧ preferably single number ratings
Hearing – sight / sound – light

Dynamic range
✧ audible magnitudes: 130dB

Frequency range
✧ 20 Hz – 20 000 Hz
   ~ \( \lambda = 17 \text{ m} \quad - \quad 17 \text{ mm} \)
✧ max sensitivity ~ 3kHz
✧ > 1300 tones

Dynamic range
eye dynamics < 90dB

Frequency range
400Tz - 790 THz
~ \( \lambda = 760 \text{ nm} \quad - \quad 380\text{nm} \)
max sensitivity ~ 555 nm
150 hues of colours
Hearing – sight / sound – light

Unique features of hearing
✧ half tone intervals \((2^{1/12})\)
✧ doubling of frequency (octaves)
✧ chords
✧ “omnidirectional character”
✧ we cannot “close our ears” like eyes
✧ acoustic memory – emotions

Do we need visualize sound?
✧ Speed: visualisation = faster analyses
listening requires more time
… and time is money …
… and western society is not only visually oriented … 😊
Society and sound insulation in Benelux

• **Noise disturbance and society classes**
  - **Grammophone**: fairly inexpensive source of music
  - Rotterdam - essential difference between music made by a musician and music generated by a device
  - 1920s and 1930s (also Haag, Leiden, Breda, Utrecht, Amsterdam, Maastricht, and Groningen)
    + include the radio

• **Discussion between left – right**
  - communists, social democrats, and left-leaning liberals, declared themselves to be against the new ordinances
  - “When I go home, I always enjoy being accompanied by music from the same radio station coming from every house of the street.”

Society and sound insulation in Benelux

• 1937: Amsterdam chief of police C. Bakker and acoustical engineer prof. C. Zwikker
  ✧ creation of a simple, low-cost pocket-size noise meter to be used by police on the streets (van Gelder)
  ✧ pocket noise meter Silenta - noise levels only above 80 dB.

• early 1950s: first provisional norm for soundproofing in housing

• 1960s – dilemmas: subjectivity of sound perception
  ✧ Prof. C.W. Kosten: one should always look for a combination of objective noise measurements and inter-subjective judgment.
Standards in sound insulation

- **In the past (ISO 717)**
  We didn’t have a look on what is happening at low frequencies
Standards in sound insulation

"L'essentiel est invisible pour les yeux"  
(what is essential is invisible to the eye)

- **recently**
  - We focus on low frequencies
  - Listening tests -> help in verification of new parameters
Standards and neighbours

- Focus on low frequencies – essential
- Middle and high frequencies shouldn’t be forgotten

Neighbors might be very different
Standards and neighbours

• Focus on low frequencies – essential
• Middle and high frequencies shouldn’t be forgotten

Neighbors might be very different and constructions too !!
Standards

• **single number ratings**
  ✦ allow for easy comparison and rankings
  ✦ simple or precise?
  ✦ compromise? … might lead sometimes to “neither fish nor fowl”
  ✦ vote for the best option?

• **in building acoustics**
  ✦ conversion of spectral sound transmission data \( R(f) \)
    to a single number quantity, \( R_w, R_w + C_x \)

• **discussions about \( R_{living} \)**
  ✦ \( R_{living} \) simplifies calculation procedure
  ✦ but does its name express what it is?
Dilema

• How do you describe a difference in single number?
How to improve the single number Rw?

- Description of "living noise": a cumbersome task
  - Different activities of various sound levels and different spectral and temporal content occur in households
  - 2 simplifications:
    1. A-weighting at low sound levels
    2. Pink noise
Listening tests – Stimuli

- **Sound samples description and collection**
  - Description of the sound source, photo-documentation …

- **Input files, recording conditions and equipment**
  - sampling rate, dynamic range
  - microphone and soundcard requirements …
  - reverberation of the room in which recordings are performed

- **Output files, playback system, stimuli presentation**
  - Calibration of frequency response
  - Calibration of the sound pressure level
Listening tests – laboratory

- Demands on laboratory for research purposes
  ◇ Low background noise levels
  ◇ Noise free, Vibration free
  ◇ Silent and preferably dry room
Listening tests – Listening people

- **Subjects (test persons, human listeners)**
  - is the only relevant measuring instrument
  - Naïve listeners and expert listeners
  - Normal hearing human subjects
  - People with known audiogram

- **Calibration of a human listener**
  - Is not possible in the same way as in case of hardware instrument
  - lack of calibration needs to be taken into account
Psychoacoustic method

- Threshold experiments
  - just audible signal, just different from another etc.

- Balance experiments
  - when a signal gives the same subjective experience as, e.g., a reference signal (loudness, pitch, duration, etc.)

- Scaling experiments
  - test signal is evaluated in relation to a numerical or sensory value

- Task experiments
  - performance of a given task, e.g., sound localization and intelligibility tests (repeating sentences/words), solving problems or other tasks, etc.

- Paired Comparisons
  - the test subject is presented with the stimuli in pairs and the subject of the two stimuli is the best, the most annoying, comfortable
  - in principle all of the stimuli in a test shall be compared to other signals. The number of comparisons is: N(N-1)/2 (N: number of stimuli)
  - with four stimuli A, B, C and D there would be six possible orders AB, AC, AD, BC, BD, CD.

- The Ranking Method
  - test subject shall arrange a limited number of stimuli according to criteria e.g., increasing loudness or annoyance: pleasantness

- Magnitude estimation
  - respond by giving a number that corresponds to the subjective perception of the stimulus

- Magnitude production
  - subject is presented for a number: task is to adjust the magnitude of the signal

- Ratio evaluation
  - sounds A, B and C

Which method is the best one for my experiment?
Examples of 2 studies

- **2 walls with the same** $R_{\text{living}}$
  - 64 different stimuli

- **5 x 2 pairs of walls with the same** $R_{\text{living}}$
  - 10 different stimuli

![Graphs showing sound attenuation](image-url)
Case study 1: (2 walls, 64 stimuli)

- Perceptual comparison of sound insulation for heavy and light-weight walls with the same rating $R_{\text{living}}$ (dB)

Reference spectra: NWIP 16717-1

Sound reduction index, $R$ (dB)
Case study 1: Stimuli

- calibrated sound recordings
  - duration 5-10 seconds

- filtered according to the given transmission spectra
  - light-weight wall (A)
  - masonry wall (B)

- calibration of headphones on artificial ear
Case study 1: Stimuli

- MUSIC
  - AC/DC
  - MILK & HONEY
  - WOLFGANG AMADEUS MOZART

- HUMAN VOICES
  - crying baby
  - reading

- PARTY
  - SWING TIME
  - JAZZ

- PINK NOISE
  - fighting couple

- MOVIE
  - Dancefloor party
  - crashing airplane
Case study 1: Stimuli

- **Stimuli**
  - Choice and preparation of stimuli

![Graph 1](image1.png)

![Graph 2](image2.png)
Case study 1: Examples of steady-state stimuli

- **pink noise**
  - Simple

- **Home cinema**
Case study 1: Subjects

- **40 subjects**
  - 35 normal hearing adults (age 20-47 years)
  - 1 normal hearing boy (age 9 years)
  - 1 older person (age 65 years)
  - 3 persons with hearing impairment (2 male and 1 female)
Case study 1: Results and analysis – Test 1

- “mass–based” walls systematically weaker than “mass-spring-mass” for the same $R_{\text{living}}$ values
  - in most cases (by normal hearing people)
- noise of a crashing airplane, reproduced via Hi-Fi
  - 35% of normal hearing said light-weight was louder
Case study 1: Results and analysis – Test 1
Case study 1: Results and analysis – Test 2

- Test 2 – overall sound level was increased with 30 dB
  - 12 subjects, 23 stimuli
### Case study 1: Results and analysis – Test 1/Test 2

- **Test 2** – overall sound level was increased with 30 dB

  ✿ Comments of subjects: "...you have put the bass sound louder...” 😊

<table>
<thead>
<tr>
<th></th>
<th>TEST 1</th>
<th></th>
<th>TEST 2 (+30dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Pink noise 80dB - home cinema</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Pink noise 80dB - HIFI</td>
<td></td>
<td></td>
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<tr>
<td>3</td>
<td>Party_Queen_Satisfaction_3</td>
<td></td>
<td></td>
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<tr>
<td>4</td>
<td>Party_Moby_1</td>
<td></td>
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<tr>
<td>5</td>
<td>Party_Moby_2</td>
<td></td>
<td></td>
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<tr>
<td>6</td>
<td>ACDC_Highway_to_Hell_1</td>
<td></td>
<td></td>
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<tr>
<td>7</td>
<td>ACDC_Highway_to_Hell_2</td>
<td></td>
<td></td>
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<tr>
<td>8</td>
<td>ACDC_Highway_to_Hell_1_min20dB</td>
<td></td>
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<tr>
<td>9</td>
<td>ACDC_Highway_to_Hell_2_min20dB</td>
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<td>10</td>
<td>ACDC_Highway_to_Hell_3_min20dB</td>
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<tr>
<td>11</td>
<td>Mozart_home_cinema_3</td>
<td></td>
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<tr>
<td>12</td>
<td>Mozart_Hifi_2</td>
<td></td>
<td></td>
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<tr>
<td>13</td>
<td>Dancefloor_home_cinema_1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>Dancefloor_home_cinema_2</td>
<td></td>
<td></td>
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<tr>
<td>15</td>
<td>Dancefloor_home_cinema_3</td>
<td></td>
<td></td>
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<tr>
<td>16</td>
<td>Dancefloor_Hifi_1</td>
<td></td>
<td></td>
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<tr>
<td>17</td>
<td>Dancefloor_Hifi_2</td>
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<td>18</td>
<td>Dancefloor_Hifi_3</td>
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<td>19</td>
<td>Dancefloor_simple_3</td>
<td></td>
<td></td>
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<tr>
<td>20</td>
<td>Dancefloor_DJ_Bobo_1</td>
<td></td>
<td></td>
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<tr>
<td>21</td>
<td>Dancefloor_DJ_Bobo_2</td>
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<tr>
<td>22</td>
<td>Film_Home_cinema</td>
<td></td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>Film_Hifi</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Case study 1: Conclusions

• Indication of a problem with $R_{\text{living}}$
  ◦ overestimation of the importance of low frequencies in NWIP ISO 16717-1 for sounds at low intensities
  ◦ A-weighting cannot be adequately applied to the assessment of sounds at low intensities, such as neighbour's noise.
  ◦ so-called "living spectrum" does not always express the living noise

• When playing transmitted sounds unrealistically high, the adequacy of A-weighting for determining a single value rating tends to improve
Case study 2: (walls, 10 stimuli)

10 walls (5 pairs with the same $R_{\text{living}}$)

$R_{\text{living}} = 39 \text{ dB}$

$R_{\text{w}}(C,C_{\text{tr}}) = 43(-3,-11)$

$R_{\text{w}}(C,C_{\text{tr}}) = 39(-1,-3)$

$R_{\text{w}}(C,C_{\text{tr}}) = 60/59(-2,-9)$

$R_{\text{w}}(C,C_{\text{tr}}) = 47(-1,-5)$

$R_{\text{w}}(C,C_{\text{tr}}) = 69(-3,-10)$

$R_{\text{w}}(C,C_{\text{tr}}) = 52(-1,-5)$

$R_{\text{w}}(C,C_{\text{tr}}) = 72(-4,-8)$

$R_{\text{w}}(C,C_{\text{tr}}) = 59(-2,-8)$

$R_{\text{w}}(C,C_{\text{tr}}) = 76(-3,-7)$

$R_{\text{w}}(C,C_{\text{tr}}) = 67(-3,-10)$

W111 CW50: 1x12,5 mm plasterboard 9,9 kg/m²

single frame CW-profile 50 mm

$150 \text{ mm AAC P4/055}$

$150 \text{ mm P4/055 AAC}$

$109 \text{ kg/m}^2$

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Case study 2: Stimuli

(1) original signals (OS)
i.e. daily life sounds with semantic content,
as transmitted through the walls

(2) inverted signals (IS) in time domain
suitable to test the effect of the presence/
absence of semantic content on the loudness
perception

(3) noise stimuli (NS) with the same spectra
as the OS sounds, but without their
semantic content and modulations
## Case study 2: Stimuli

<table>
<thead>
<tr>
<th>Sound Nr.</th>
<th>Sound example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sound 1</td>
<td>PINK NOISE L80 dB</td>
</tr>
<tr>
<td>Sound 2</td>
<td>PINK NOISE L100 dB</td>
</tr>
<tr>
<td>Sound 3</td>
<td>Argument L75 dB</td>
</tr>
<tr>
<td>Sound 4</td>
<td>BARKING OF A BIG DOG L85 dB</td>
</tr>
<tr>
<td>Sound 5</td>
<td>BABY CRYING 3 L80 dB</td>
</tr>
<tr>
<td>Sound 6</td>
<td>LATINO - A La P.P. L80 dB</td>
</tr>
<tr>
<td>Sound 7</td>
<td>LATINO - A La P.P. L100 dB</td>
</tr>
<tr>
<td>Sound 8</td>
<td>METAL 2 - Rumburax Sad Happiness L80 dB</td>
</tr>
<tr>
<td>Sound 9</td>
<td>METAL 2 - Rumburax Sad Happiness L100 dB</td>
</tr>
<tr>
<td>Sound 10</td>
<td>PARTY L85 dB</td>
</tr>
</tbody>
</table>

Sound 1 and Sound 2 were only presented out of the “original sound” stimuli pool.
Case study 2: Stimuli

- Time evolution of the A-weighted sound pressure level (integration time ‘fast’, i.e. 125 ms) for the party sound signal in the receiving room for the two scenarios under study, i.e. filtered by the transmission spectra of the heavy weight and light-weight wall.
Case study 2: Subjects

• 22 normal hearing test persons
  ◇ (N = 22, ♂ = 5, ♀ = 17) between 23 and 58 years of age
  ◇ Belgium, Mexico, Morocco, France, Albania, China, Czech republic, Spain, Slovakia and Austria
  ◇ Each test person was seated in the anechoic chamber in order to avoid background noise or distraction from other people
Case study 2: Listening test - procedure

- response format => refined with two additional response categories
- to keep the guessing rate low and to encourage the test persons to reason more thoroughly if the stimuli comparison presented was not unambiguous
Case study 2: Results and analysis

(1) “original” sound stimuli comparison

To check the reliability, 20 test persons accomplished the re-test after a 1-2 weeks

A retest reliability coefficient $r_{tt} = 0.8$, means a quite good reliability

(2) “inverted” sound stimuli comparison

(3) “noise” sound stimuli comparison
Case study 2: Conclusions

- “original” vs “inverted” scenarios were not significantly different

- “original” and “reverse” vs “noise” condition showed different responses and need to be further investigated

- According to the results the proposed $R_{\text{living}}$ doesn’t describe both construction modes (traditional masonry walls and light weight walls) with the same accurateness

- Sound stimuli transmitted through the wall based on only mass examples were systematically perceived as louder

- Only if the wall pairs with the highest sound insulation of the chosen 5 are compared, the results are not obvious
Case study 2: Conclusion

- Indication of problem with $R_{w,\text{living}}$
  - overestimation of the importance of low frequencies
  - so-called "living spectrum" does not always express the living noise
  - A-weighting cannot be adequately applied to the assessment of sounds at low intensities, such as neighbour's noise

- $R_{\text{living}}$ good parameter for estimation of low frequencies and not living room noise

- Would renaming it to $R_{\text{bass}}$ or $R_{\text{low}}$ be a good compromise?

- ... and even then... how can we actually measure at frequencies < 100 Hz??
Thank you for attention

• ... and even then... how can we actually measure at frequencies < 100 Hz ??
• will be presented soon by my colleague called also “Mr. 1000- sticker”