The Role of Acoustics in Curtain Wall Design:
Strategies to Achieve Desired Performance Criteria

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Goals

• Basics of Acoustics
• Ratings in Architectural Acoustics
  – Single Number Metrics
  – Code Requirements
• Acoustical Performance of Curtainwall
  – Elements that affect noise level
  – Effect of glazing parameters
• Noise from Curtainwall Systems
• Sound Isolation at Vertical Condition
• Sound Isolation at Horizontal Condition
Acoustics Basics
What is Sound?

• Sound is short-term pressure fluctuations that propagate through a medium

• In air, it is a pressure wave of fluctuations above and below atmospheric pressure
The decibel (dB) is used to measure sound level and is a logarithmic unit that describes a ratio.

Sound levels add logarithmically:
- $93\,\text{dB} + 93\,\text{dB} = 96\,\text{dB}$
- $80\,\text{dB} + 90\,\text{dB} = 90\,\text{dB}$

Subjective reactions vary in the population. These are the rules of thumb regarding change:
- A change of around 3 decibels is just noticeable
- A change of around 6 decibels is obvious
- An increase of about 10 decibels is perceived as twice as loud.
Sound Levels of Various Sources

- Threshold of Hearing: 0
- Quiet Suburban Nighttime: 20
- A Human Voice: 60
- Food Blender at 3': 80
- Jet Takeoff at 200': 120
- Library: 10
- Noisy Urban Daytime: 70
- Rock Band: 130
Sound Levels of Various Sources

- Typical exterior sources:
  - Remote farm
  - Quiet Street
  - 150 ft from dense traffic
  - Airplane 3000 ft overhead
  - Under elevated train structure
  - Noisy street
  - Edge of busy highway

- Typical interior sources:
  - Quiet residence
  - Passenger auto
  - Radio playing
  - Private office
  - Business office
  - School cafeteria
  - Factory office
  - Aircraft cabin
  - Radio broadcast studio
  - Retail store
  - Typical factory workplaces

- Typical sound levels at 3 ft from source:
  - Quiet A/C outlet
  - Noisy A/C outlet
  - Business machines
  - Power saws
  - Textile looms
  - Punch press/riveter
  - Quiet talker
  - Loud talker
  - Wood planer

- Sound level, dBA:
  - 20
  - 30
  - 40
  - 50
  - 60
  - 70
  - 80
  - 90
  - 100
  - 110
  - 120
Sound Frequency

- Frequency is how quickly the wave oscillates.
- Frequency is related to the pitch of a sound.
- Measured in Hertz (Hz) = cycles per second.
Sound as a Function of Frequency

- OSHA limit for 8-h exposure
- Pneumatic air jet
- Approximate range of normal continuous speech
- Typical centrifugal air-conditioning fan
- Approximate threshold of hearing for continuous sounds
Equal Loudness Contours

[Graph showing equal loudness contours with sound pressure level in decibels on the y-axis and frequency in cycles per second on the x-axis.]
Acoustical Ratings: Single-Number Metrics
Important Ratings in Architectural Acoustics

\( L_{eq} \)  
**Equivalent Level**  
The average noise level over a specified time period (often 1 hour)

**Community Noise Equivalent Level**

**Day-Night Noise Level**  
Both are a noise description of the 24 hour average noise level, taking into account humans’ increased sensitivity to noise in the evening and nighttime.

**Sound Transmission Class**  
A single number rating for assessing speech transmission through a structure

**Outdoor-Indoor Transmission Class**  
A single number rating for assessing traffic noise transmission through a structure
Sound Transmission Class

- Test procedure defined in ASTM E90 (laboratory) and E336 (field)
- Noise is generated in source room
- Measure noise levels in receiving room in third-octave bands from 125–4000 Hz
Reference Contours

Noise reduction or transmission loss

STC 55

IIC 55

Better
STC Example
STC Example

5 7 6 4 1 1 2 1 = 27
STC Example

STC 47

5 7 6 4 1 1 2 1 = 27
Single Number Ratings – STC

Intent: a single number rating to compare isolation of different assemblies.

These single-number ratings correlate in a general way with subjective impressions of sound transmission for speech, radio, television, and similar sources of noise in offices and buildings.

Limitations:

• Only appropriate for noise sources with a sound spectrum similar to the reference contour.
• Does not deal with low frequency noise (<100 Hz)
Single Number Ratings – OITC

Intent: a single number rating to assess the isolation provided of different assemblies specifically for traffic and aircraft noise.

These ratings provide an evaluation and rank ordering of the performance of test specimens based on their effectiveness at controlling the sound of a specific outdoor sound spectrum.

Limitations:

• Intended for traffic and therefore assumes a particular traffic spectrum that does not hold for all locations.
• Uses 80 and 100 Hz octave bands which have higher uncertainties in laboratory measurement.
• Limited evidence to show improvement over STC
• A good approximation is STC – 6.
Exterior Façade Design
Exterior Façade Design

1. Define Exterior Noise Environment
   a. Measure
   b. Model

2. Calculate Interior Noise Level
   a. Transmission Loss (STC)
   b. Radiating Area
   c. Room Absorption

3. Which window?
   a. Glazing types
   b. Characteristics
   c. Breakpoints
Measurements
Noise Model

- Quick and accurate model generation based on project drawings with 3D terrain data.
- Predict exterior noise levels with changing terrain and barriers.
- Predict exterior noise levels with height up the building façade, above where it is practical to measure.
## What Do We Measure?

<table>
<thead>
<tr>
<th>Metric</th>
<th>Description</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>LDN or CNEL</td>
<td>Average Daily Exposure</td>
<td>General acceptance. Code/General Plan compliance.</td>
</tr>
<tr>
<td>Lmax</td>
<td>Typical Short-Duration Noise Event</td>
<td>Sleep disturbance. Intrusiveness.</td>
</tr>
<tr>
<td>Spectrum</td>
<td>Relative balance of low and high frequencies</td>
<td>Very important for designing glazing</td>
</tr>
</tbody>
</table>
Average vs. Maximum Levels
One Equation To Rule Them All

\[ \text{SPL}_{\text{inside}} = \text{SPL}_{\text{outside}} - TL + 10 \log S - 10 \log A + C \]
One Equation To Rule Them All

\[ SPL_{\text{inside}} = SPL_{\text{outside}} - TL + 10 \log S - 10 \log A + C \]
One Equation To Rule Them All

\[ SPL_{\text{inside}} = SPL_{\text{outside}} - TL + 10 \log(S) - 10 \log(A) + C \]

- Transmission Loss
- Radiating Area
- Doubling window area = 3 dB increase
One Equation To Rule Them All

\[ SPL_{inside} = SPL_{outside} - TL + 10 \log S - 10 \log A + C \]
## Glazing Types

<table>
<thead>
<tr>
<th>Glass type</th>
<th>Typical STC Range</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single plate</td>
<td>24-29</td>
<td>Not used.</td>
</tr>
<tr>
<td>Dual plate</td>
<td>26–35</td>
<td>Standard residential.</td>
</tr>
<tr>
<td>Dual, lam over plate</td>
<td>33-38</td>
<td>Typical acoustical product.</td>
</tr>
<tr>
<td>Dual, lam over lam</td>
<td>33-38</td>
<td>Increased LF performance.</td>
</tr>
<tr>
<td>Single lam</td>
<td>33-42</td>
<td>Not typical because of Title 24.</td>
</tr>
<tr>
<td>Triple</td>
<td>40-50</td>
<td>When high isolation required.</td>
</tr>
</tbody>
</table>
The Problem with Dual-Glazing
Dual vs. Single Laminated

½” Lam STC 37
Triple Glazed or Storm Window
The Importance of Airspace

Triple Glazed Assemblies

- 4”+
- 3-4”
- 2-3”
- <2”

Since 1947
Not Just About the STC!

Transmission Loss (dB)

Third Octave frequency (Hz)

Brand X
Average STC 37

Very poor around 125 Hz
Not Just About the STC!

<table>
<thead>
<tr>
<th>Glazing</th>
<th>STC Rating</th>
<th>Resultant Interior Noise Level (CNEL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average STC 37</td>
<td>37</td>
<td>45</td>
</tr>
<tr>
<td>No lam, 1” airspace</td>
<td>37</td>
<td>49</td>
</tr>
<tr>
<td>Lam, 1” airspace</td>
<td>40</td>
<td>46</td>
</tr>
<tr>
<td>Lam, 5/8” airspace</td>
<td>40</td>
<td>45</td>
</tr>
</tbody>
</table>
Effects of Glazing Parameters

Transmission Loss (dB)

Third Octave Frequency (Hz)

Average STC 37

Laminated glass and smaller airspace

Change to laminated glass

Original
Noise of Curtainwall
Popping

- Occupant complained for popping or pinging noises from the curtainwall.
- Sound level as high as 50–55 dBA. Vibration can be felt in mullions.
- Top floor, two-story space, very large curtainwall relative to floor area.
- Only occurs during daytime; temperature change suspected.
Temperature Measurements

High air temperature was 91 deg F.
Deflection

- Vertical movement of mullion of 0.140” (3.55 mm).
- Horizontal movement of mullion of 0.090” (2.29 mm).
- Aluminum framing shows marks of rubbing during movement.
Mitigation

Additional steel angles may be required.

New Steel anchor for living room mullion to replace cont. aluminum extrusion.

Additional to vertical drill & tap.

Pipe spacers req’d to allow for movement.

4" 3/8 or 1/2" bolt, drill & tap on nut & bolt. Bolt size and quantity to be confirmed by structural engineer.
Vertical Noise Isolation at Mullions
Vertical noise transmission between offices at corner mullion condition
Gaps at Edge-of-slab Condition
Mitigation

- Frame horizontal gypsum board closure about 12” below existing.
- Caulk to ceiling and glass.
- Fill cavity with insulation.
Mitigation Results

![Graph showing noise reduction in decibels (dB) before and after application of a mitigation technique. The x-axis represents third octave frequency in Hertz (Hz), ranging from 100 to 4000 Hz. The y-axis represents noise reduction in dB, ranging from 10 to 60 dB. Two lines are plotted: one for 'After' and one for 'Before'. The 'After' line shows a significant reduction in noise across all frequency bands compared to the 'Before' line.]
Mitigation Results

Large improvement below 500 Hz.

Smaller improvement above 500 Hz. This region is believed to be associated with transmission through the mullions themselves.
Another Edge-of-Slab (Wood joist building)
Mitigation

Large improvement at most frequencies. Smallest improvement at 1000 Hz which is mullion transmission.
Sometimes the Mullion Transmission Is a Problem...

At one curtainwall, the transmission was at 1000 Hz was extreme.
Mitigation

• Holes drilled in mullion at floor above.
• Acoustical caulk pumped into mullion to fill the mullion for the height of the spandrel.
• About 14–18 inches high.
Mullion Mitigation

Transmission at 1000 Hz and higher greatly reduced.
Horizontal Noise Isolation at Mullions
How Much Isolation You Need...

- Low: STC Rating 30-40
- Middle: STC Rating 50
- Higher: STC Rating 60-70
- Luxury: STC Rating 70
...Defines What Type of Mullion Detailing You Need

STC Rating

30  40  50  60  70

[Images of various mullion detailing examples]
...with thought to FLANKING CONSIDERATIONS

- This condition occurs in primarily concrete structure
- Mullions/windows
- Curtain wall connections to slab
- Floor conditions
- Ceiling (slab) conditions
- Interior intersection details
- Penetrations
- *Curtain wall intersection at wall*
Bare Mullion
Wrapped mullion
Effect of wrapping mullion

STC 44

STC 48
Trim piece
Trim Piece
Effect of Trim Piece

NIC 51, 51
NIC 50, 48, 46
NIC 48, 46
Trim piece with seals
Wide or double mullions

UNIT B-1

UNIT B-3

1'-2"
Wide or double mullions
Wide or double mullions

NIC 51–56
Double mullions with closure
Double Mullion with Closure
Double mullions with closure

NNIC 62, 62, 68
Effect of Ceiling Flanking
## Summary Chart

<table>
<thead>
<tr>
<th>Condition</th>
<th>Wall Min STC</th>
<th>Mullion</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low (Office)</td>
<td>STC 40</td>
<td>Exposed</td>
<td>STC 35–40</td>
</tr>
<tr>
<td>Mid-level (Hotel)</td>
<td>STC 52</td>
<td>Wrapped or trim Trim</td>
<td>STC 46–53</td>
</tr>
<tr>
<td>Mid-High (Hotel, School, Condominium)</td>
<td>STC 58</td>
<td>Widened/double</td>
<td>STC 52–56</td>
</tr>
<tr>
<td>Luxury (Condominium)</td>
<td>STC 60+</td>
<td>Widened/double with closure</td>
<td>STC 60+</td>
</tr>
</tbody>
</table>
Effects of Mullion Flanking

STC 44
STC 48
STC 49
STC 53
STC 64
Commercial Products
Summary

• Single Number Ratings
  – Noise levels typically measured as DNL or CNEL
  – Curtainwalls specified in terms of STC and OITC
  – Single numbers do not tell the whole story

• Acoustical Performance of Curtainwall
  – Exterior noise level, glazing area, acoustical room absorption will all affect the requirements for the glazing.
  – No single number can convey all of the effects – do not design to a rating.
  – Type of glass, thickness of glass and airspace have specific effects on the performance at various frequencies.

• Noise from Curtainwall Systems
  – Curtainwalls can generate noise due to friction or binding under thermal expansion.

• Sound Isolation at Vertical Condition
  – Edge of slab requires a solid acoustical block of some sort
  – Sound transmission through the curtainwall itself is sometimes a problem.

• Sound Isolation at Horizontal Condition
  – Sound transmission through mullions requires careful consideration.
  – The level of protection is determined by the required performance.
Thanks for your attention!