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The Acoustic Performance of Double-Skin Glass Facades:

A Design Support Tool For Architects

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ABSTRACT: This study assesses and validates the influence of sound in the urban environment and glass façade components in responsively reducing sound transmission to the indoor environment. Among the most reported issues affecting workspaces, increased awareness to minimize noise led designers to reconsider the design of building envelopes and its site environment. Outdoor sound conditions, such as traffic noise, challenge designers to accurately estimate the capability of glass façades in acquiring an appropriate indoor sound quality. Field-measurements for sound transmission loss can establish a baseline performance in a context for sound levels common in urban areas. INSUL is a sound insulation software utilized as an informative tool correlating glass façade parameters with the outdoor sound level based on ISO 717 to predict indoor sound levels. This study validates the acoustic performance of glass facades early in a project's design through prediction methods and acoustic field-testing. Results from the study support that acoustic comfort is not limited to a singular solution, but multiple design options responsive to its environment.

Keywords: acoustic, urban noise, sound transmission loss, indoor environmental quality, double-skin facade, design support

1. INTRODUCTION

One of the most frequently reported issues of indoor environmental quality (IEQ) affecting workspaces is noise breaking through the building façade. This concern has led building designers to reconsider the building envelope with regard to its performance resisting outdoor sound (Acoustics Continuing Education Unit 2009). The visual aspects of glass facades allow natural daylighting and transparency between the exterior and interior with the objective of improving IEQ, occupant comfort and productivity. In contrast to the available design guidance for other environmental aspects of the building façade, the influence of acoustics contributing on workspace comfort is not fully realized until after project completion. Determining and understanding the acoustic performance for glass facades during design remains a challenge for most projects, and is an area where designers are limited with acoustic guidance. Improved acoustic design guidance for building enclosures is needed to increase awareness of acoustic quality and its influence on occupant comfort. The intent of this study is to aid designers in making informed decisions for envelope design and material selection appropriate to the acoustic environment of the project site.

2. PROBLEM STATEMENT

While advances in design tools and facade performance criteria primarily focus on daylighting, thermal performance, and ventilation, acoustic design is often not the highest priority. Among these factors, the impact of acoustic performance in affecting workspace comfort is underestimated and confronted in every design project (Paradis 2012). Due to urban density, urban noise, and increasing levels of urbanization, designing towards acoustic comfort is an increasing design challenge. As urban environments vary, façade design solutions for one setting may not be applicable to, or effective in another. Each design project and each façade elevation requires sensitive consideration and response to site-specific acoustic conditions and material choices.

3. METHOD

The objective of this research is to provide acoustic design guidance to assist architects in designing glazed facades in areas where significant control of outdoor sound is needed. The approach is aimed at acoustic design support during early stages of design decision-making.

Methods included field-measurements using a hand-held sound meter device, and sound transmission simulations using INSUL, a sound insulation prediction software (INSUL 2011). Sound levels measured from field-measurements and INSUL simulation results were graphed on Microsoft Excel. Field-measurements were directly exported from the Decibel 10th application into Microsoft Excel. As an iPhone application, Decibel 10th is utilized as a sound meter that measures sound pressure levels. Composed by SkyPaw Ltd., Decibel 10th detects sound levels ranging from 0dB to 110 dB. Within the given timeframe, it identifies peak sound levels and maximum sound levels. Although Decibel 10th is not classified as Class I equipment, the iPhone application is used as relative measurement tool. It serves as a diagnostic tool to compare the relative difference between measurements.

Documenting its peak values in decibels, sound data was organized to compile indoor conditions and outdoor conditions for an overall comparison. Comparing the indoor condition to its actual outdoor condition was also documented to determine the acoustic performance of each condition's building enclosure. Implementing field-measurements, INSUL simulations in compliance with ISO standards, analytical simulations were obtained to provide realistic levels of traffic noise.

Focusing on sound transmission loss solely from façade assemblies, this study identifies indoor sound levels to derive from sound transmission loss from the building façade, dismissing room parameters influencing indoor sound levels. Although this research study focuses on sound transmission loss from façade components and parameters, INSUL simulations also determined room and façade parameters, such as room volume, reverberation time, and façade area, to influence sound transmission loss. Graphs for each simulation display outdoor sound levels, amount of transmission loss, and resulting indoor sound levels below 5000 Hertz. Graphs were initially classified by glass type and glass thickness for single-glazed facades and single-skin facades since building envelopes from field-tests were constructed of single-glazed facades.

Single-glazed facades contain one glass panel. Since the medium for six field-test sound conditions were single-glazed facades, single-glazed facades were simulated to determine the acoustic performance a façade with a single glazing. In this study, single-skin facades are composed of an insulated glazing unit, IGU. Standard dimensions for IGU is of two quarter-inch (1/4") glass panels separated by half-in (1/2") air space (Fig.1). For double-skin facades, graphs were also classified by glass type and glass thickness, along with air-cavity depth. Double-skin facades consist of an inner skin and outer skin-the secondary glazing separated by a specified air-cavity depth. The inner skin of double-skin facades are commonly composed of IGUs while the outer skin is a single glass panel; however, both skins can be composed of IGUs.

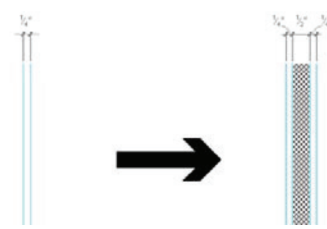

Fig. 1: Diagram (left to right) Single-glazed and single-skin

Simulated single-glazed facades and single-skin facades of three glass types were classified into three charts.

1. Monolithic glass
2. PVB laminated glass
3. TSC laminated glass

With each graph focusing on a glass type, it displays the indoor sound levels for industry-standard glass thickness. Glass thickness is indicated by its shade of color, the darkest shade corresponds to the largest dimension and lightens as the dimension decreases. Double-skin facades followed the same format as sealed single-glazed facades and sealed single-skin facades.

1. Monolithic glass
2. PVB laminated glass
3. TSC laminated glass

3.1. Field Testing

Field-testing is performed to measure and establish baseline outdoor acoustic information, and to examine the efficacy of conventional curtain wall assemblies in reducing sound transmission. Measurements were taken at six existing sites in Los Angeles of office and study workspace occupancies (Table 1). Sites were selected from mapping high employment density and midday vehicular traffic, indicating a concentration of activities that are common noise conditions in an urban environment (Fig. 2). Noise conditions at sites included vehicular traffic and aircraft noise. Indicating traffic congestion as red line segments, mapped street traffic was attained from Google Maps' interactive traffic feature. Each site was recorded and documented within closely related conditions. In measuring and recording indoor sound levels, an iPhone, utilized as a sound meter using the Decibel 10th application, was situated no more than 3 meters from glazed facades. In efforts to respond to sound levels affecting the workspace environment, all field tests were conducted on weekdays between 12:00–15:00, during active business hours. To compile a range of sound levels and reduce isolated test conditions, outdoor and indoor sound conditions were measured and recorded within a 4-minute timeframe (Fig. 3-6).

It is fundamental to identify and understand the influence a façade design has on a workspace environment and its site conditions. Among the most challenging sound conditions is traffic noise, a common condition in the urban environment. Serving as initial measurements, the highest sound level obtained from field-testing- the most extreme condition, was implemented to weigh traffic sound spectrum simulated in INSUL, ISO 717. ISO 717, a rating of sound insulation in buildings and of building elements: airborne sound insulation, is defined as single-numbered values for airborne sound insulation in buildings and building elements, such as walls, flooring, doors, and windows (ISO 717).

Field-measurements were used as a correction factor to INSUL's ISO 717 traffic noise prediction method to resemble the outdoor sound environment results in increasing the accuracy of simulations. Field-measurements provided single-figured dB levels. Implementing field-measurements in INSUL's ISO 717 traffic noise prediction method, a 1/3-octave band sound spectrum was obtained. This strategy aims toward enabling designers to determine design goals to reduce sound transmission through the facade.

TABLE 1: FIELD-TEST SITE CONDITIONS

Condition	*Exterior*	*Interior*	*Area*	***Outdoor 4:00***	***Indoor 4:00***
1	**Downtown LA Bunker Hill**	**Central Library**	**Business**	**60-100dB**	**49-67dB**
2	**Downtown Culver City**	**Office**	**Business**	**42-87dB**	**45-76dB**
3	**LAX Arrival**	**Arrival**	**Transit**	**65-90dB**	**57-75dB**
4	**LAX Departure**	**Departure**	**Transit**	**68-84dB**	**57-82dB**
5	**USC**	**Tutor Hall**	**Education**	**59-79dB**	**41-71dB**
6	**USC**	**GER Library**	**Education**	**50-75dB**	**40-65dB**

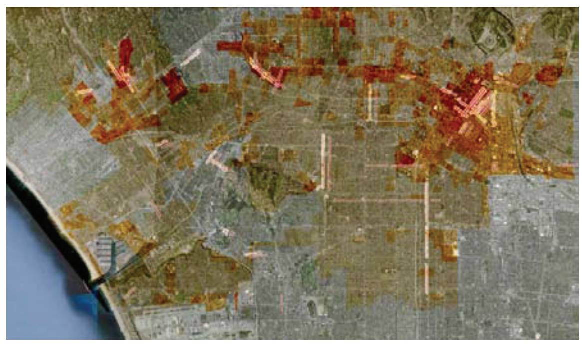

Fig. 2: Mapped sound levels in Los Angeles: Intensity of red indicating increased sound levels with reference to concentrated traffic (staggered streaks)

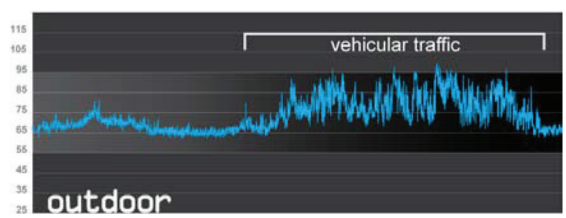

Fig. 3: Field-tested outdoor sound level: Bunker Hill & LA Central Library

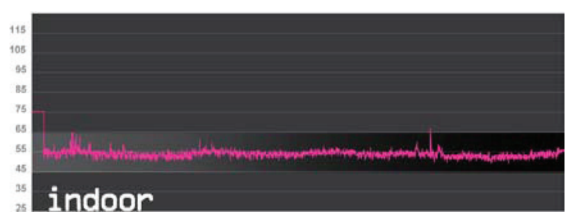

Fig. 4: Field-tested indoor sound level: Bunker Hill & LA Central Library

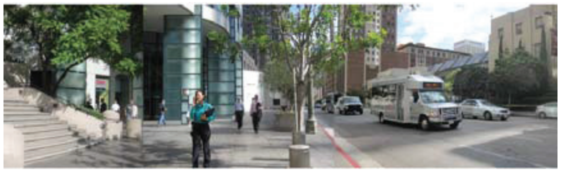

Fig. 5: Field-tested outdoor condition: Bunker Hill

Fig. 6: Field-tested indoor condition: LA Central Library

3.3 Sealed Single-Glazed Facades and Sealed Single-Skin Façades

The intent of assessing sound transmission loss from glass facades through simulations was to further analyze the performance of double-skin glass facades in reducing sound transmission from immediate distanced outdoor levels within frequencies to 5000Hz. Frequencies indicate the number of cycles-per-second (cps) a sound pressure wave repeats in hertz (Hz) and is used to determine the audible range of human hearing, 20Hz to 20,000 Hz. Sound levels measured at 5,000 Hz are audible to humans. Sound levels (dB) indicate whether the audible sound source is identified by the human ear as sound or noise.

In accordance to EN ISO 717, varying conditions of sealed facades were simulated (British and International Standards 1997). Weighting ISO 717 sound levels with the maximum outdoor sound level from field-tests, 90dB, increased the accuracy of simulations to resemble a realistic setting as well as adjust sound levels to be audible Since field-test conditions consisted of single-glazed facades, 12 single-glazed facades were simulated in INSUL to determine the acoustic performance of a façade with single-glazing (Fig. 7).

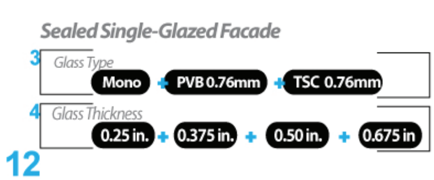

Fig. 7: Classified conditions indicating number of simulations achieved for sealed single-glazed facades

In analyzing the acoustic performance of single-skin facades, 12 iterations derived from variables such as glass type and glass thickness. Selected glass types, such as monolithic, PVB Laminated Glass (PVB), and Trosifol Laminated Glass (TSC), and glass thickness simulated for this study are typical models in the most glass manufacturing companies. five standard glass thickness were analysed (Fig. 8).

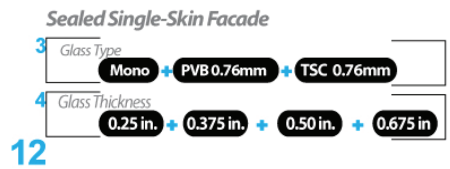

Fig. 8: Classified conditions indicating number of simulations achieved for sealed single-skin facades

Comparing transmission loss obtained from both forms of façade assemblies (single-glazed and single-skin) determined the amount of transmission loss improved by adding an additional glazing. In addition to comparing sound transmission loss in field-tested conditions and simulated conditions, data obtained from field-tests served to validate the accuracy range of INSUL's estimations. Demonstrated to provide sound transmission loss estimations within close range of single-glazed facades field-tested, double-skin glass facades were modelled and simulated within the same INSUL configurations used to simulate sealed single-glazed facades and sealed single-skin facades.

3.4. Sealed Double-Skin Glass Façade

Using INSUL, sealed double-skin facades composed of three glass types were simulated under varied components. Considering standard parameters, three glass types, four thickness and four air-cavity depth, 48 were analyzed (Fig. 9).

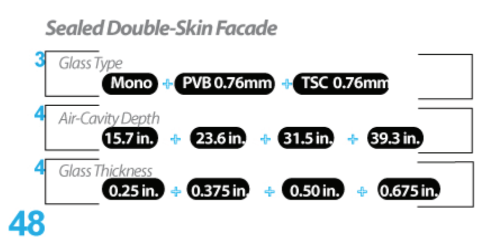

Fig. 9: Classified conditions indicating number of simulations achieved for sealed double-skin facades.

4. RESULTS

With field-measurements involving single-glazed facades as its enclosure, measured and recorded site conditions served as a baseline differentiating outdoor sound levels and indoor sound levels (Table 1). Identifying differentiations between outdoor and indoor conditions in decibels (dB), its highest noise levels for traffic was implemented into simulated sealed single-skin facades and sealed double-skin facades. Obtained from field-tests, inputting the highest outdoor sound level to weight INSUL's standard traffic noise (ISO 717) provided a more realistic setting for the analysis.

Sound transmission loss (dB) obtained using INSUL were ordered by four standard glass thickness and separated based on the three laminate types: monolithic, PVB, and TSC. All graphs display the same outdoor sound level used in simulations as a white horizontal segment. It serves as a reference line to determine the magnitude of sound transmission loss due to varying parameters.

Simulated sealed single-glazed facades and sealed single-skin facades were composed into 3 charts separated by glass type. Displaying the influence of glass type and glass thickness in reducing sound transmission, indoor sound levels resulting from the remaining outdoor sound level transmitted through IGUs of four standard *glass thickness correspond to a shade of a given color*. The darkest shade of a given color indicates the thickest glass simulated. Sharing the same given color, each shaded segment indicates the indoor sound levels of a glass thickness. As the darkest shade indicates the largest glass thickness, lighter shades represent the smaller glass (Fig. 10).

For sealed double-skin facades, results were formatted similarly to the results for sealed single-skin facades; however, considering an additional component, air-cavity depth, require graphs to be separated based on glass thickness and glass type. Instead, the color-shaded plots indicate the air-cavity dimension. Three charts of the same glass thickness consist of four horizontal plots, indicating four standard air-cavity dimensions. Displaying indoor sound levels within frequencies of 5,000Hz, graphs separated by thickness and glass type compare the acoustic performance of air-cavity dimensions (Fig. 11). Comparison from single-glazed facades to single-skin facades, and single-skin facades to double-skin facades validated improved transmission loss.

4.1. Sealed Single-Skin Facades

Sealed Single-skin facades with laminated glass, either PVB or TSC, provided significant transmission loss in mid-frequencies. Using PVB laminated glass increased transmission loss by increasing glass thickness in mid-frequencies while smaller thickness provided greater transmission loss in higher frequencies. Although TSC laminated glass is claimed by product manufacturers to improve transmission loss by at least 3dB compared to PVB laminated glass, this study determined TSC to improve transmission loss by 1dB (Kuraray Trosifol).

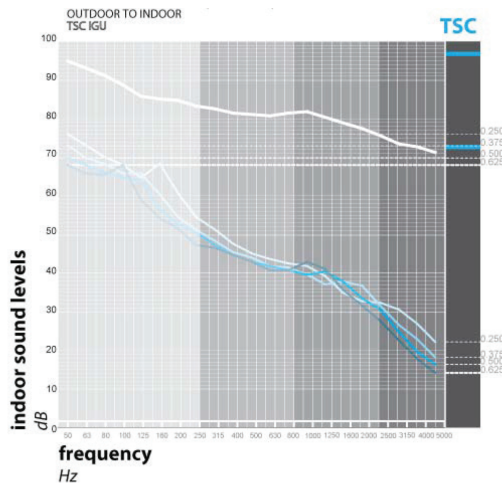

Fig. 10: Sealed single-skin façade under ISO 717, TSC

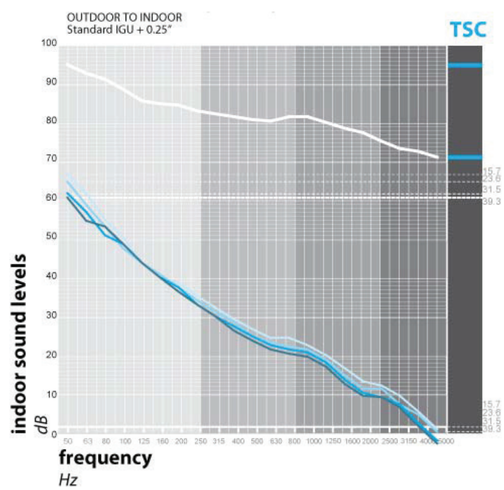

Fig. 11: Sealed Double-Skin Façade under ISO 717, TSC

4.2. Sealed Double-Skin Facades

Increasing the air cavity depth for double-skin facades effectively reduced sound transmission within higher frequencies. Towards lower frequencies, air-cavity depth linked with maximum glass thickness improved sound transmission loss. Although double-skin facades dramatically reduce sound transmission in comparison to single-glazed facades and single-skin facades, increasing the air-cavity depth minimally improves sound transmission loss by 1 to 2 dB.

Simulating sealed single-glazed facades, sealed single-skin facades, and sealed double-skin facades, increasing the air-cavity dimension provides increased sound transmission loss in comparison to glass thickness.

5. DISCUSSION AND CONCLUSIONS

Using INSUL simulations configured to resemble realistic settings, sealed double-skin facades demonstrated to improve sound transmission loss. However, responding to higher frequencies, the amount of sound transmission loss was not dramatic as transmission loss achieved within frequencies below 500Hz.

Field-testing is a fundamental procedure that reflects noise conditions in the current environment. In determining the components of a building's glass facade, measuring existing conditions of its site enable building designers to specifically address to its sound environment. As field-tests were conducted in Los Angeles' most concentrated commercial areas and traffic intersections, the simulations and design support tool provides designers design solutions that would specifically respond to its current context.

Composed from INSUL simulations and field-testing, the design support tool enable building designers to compare transmission loss based on façade components within frequencies below 5000 Hz (Fig. 12).

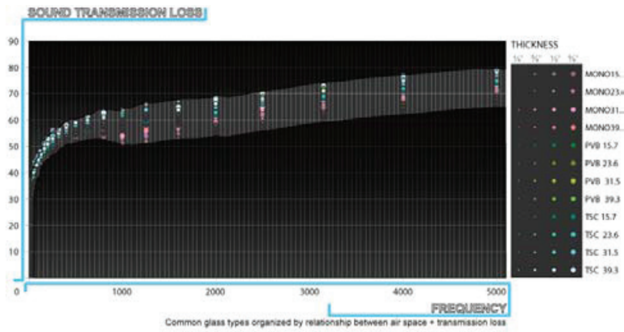

Fig. 12: Design support plot for double-skin facades: Common glass types organized by relationship between air space and transmission loss.

Utilizing this study's approach can increase building designers' awareness in designing glass building enclosures and its response to its acoustic environment. This study approach demonstrates the careful consideration necessary to provide acoustic comfort. As the methods conducted in this study redefines acoustic design for glass facades, it provides designers the opportunity to collaborate with the city in continuing efforts to improve indoor acoustics as well as environmental acoustics.

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