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Sound Transmission through Aluminum Framings of Window, Door and Façade Systems

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ABSTRACT

Recent environmental regulations bring up higher standards on acoustic comfort. Mitigating the noise transmission from façade exterior to interior is rising as an important issue in building envelop designs. Modern façade systems consist of aluminum frames and multiple high-performance layers of insulating or laminated glass. Thus, the overall sound insulation of such systems depends not merely on glasses but might more on frames and the coupling between them. Particularly when the STC of glass reaches 40 or higher, the sound path through the framing elements becomes more critical. However, this crucial issue has not received enough investigation, and no satisfactory approach has been developed in the literature yet. This issue is addressed by studying the coupling between aluminum frames and glazing infill, and an extended model has been accordingly developed. A series of laboratory tests with different frames were conducted to validate the predictions. As an application of this research, a design-orientated simulating platform has been developed to provide quick estimations of the sound insulation performance of window and façade systems.

Keywords: Sound, Insulation, Transmission Loss, Aluminum Frame, Window, Facade

1. INTRODUCTION

Aluminum-framed window has become a prevailingly popular choice for commercial and residential high-rise buildings. Due to the high strength of the aluminum material, it offers a large daylight opening to frame ratio at a relatively low purchase cost. The narrow frame width is of particular importance for modern curtain wall designs.

Meanwhile, Aluminum has material that has high durability and longevity properties that performs well under harsh weather conditions. Also, with the high-quality thermal broken design, high energy efficiency window and façade systems have been evolved tremendously over the past few years, which offers exceptional performance through thermal insulation and water – air tightness. Compared to the efforts dedicated to improving the thermal performance, much less attention has been paid to the acoustic performance of Aluminum-framed window systems so far. With the rapid urbanization over the world, environmental noise pollution has become a bigger concern, especially for residential construction in noisy areas. However, there is not a satisfactory approach developed yet to address this critical issue up to date systemically.

The overall sound insulation of an Aluminum-framed window depends not merely on glasses but might more on frames and the coupling between them. It is common practice for window manufacturers and fabricators to obtain acoustic performance of a window system by conducting laboratory "sound transmission loss" experiments. Laboratory test does provide a straightforward way to access the sound transmission characteristics. However, numerous evidence showed that poor repeatability among different laboratories exhibits. Also, it suffers from time and expense cost to

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conduct a series of tests. Moreover, each window system has its profile details and glazing selections, making it far expensive to target a series of test of a complete system.

Because of the high complexities of airborne interactions and sound transmission paths cross the Aluminum-framed window system, it is increasingly challenging to evaluate the overall acoustic performance of a framed window system. For this reason, very limited theoretical models can be found in the literature so far.

The effort of this study is to tentatively characterize the overall sound transmission of the aluminum-framed window system. The coupling between aluminum frames and glazing infill will be carefully studied, a series of laboratory tests with different glazing options are conducted and analyzed, through which a feasible method will be proposed to predict the aluminum window transmission loss in 1/3 octave bands frequency. As an application of this research, a design-orientated simulating platform has been developed to provide quick estimations of the sound insulation performance of window and façade systems.

2. METHODOLOGY

The approach used in this paper to estimate the overall window acoustic performance is the following. Firstly, the daylight opening area in the window frame is shielded of high sound insulation masking panel from the sound field. Heavy panels are attached to the vision area to block the sound path and the masked window setup is tested. Then, the acoustic performance of the composite mask is measured by adjusting the opening size of the filler wall and installing the mask without a frame.

The frame sound transmission coefficient can be reverse calculated using the following equation: $R_{total} = -10\, log_{10}(\frac{1}{\sum_{n=1}^{N} S_n} \sum_{n=1}^{N} S_n \tau_n)$, where R_{total} is the framed mask transmission loss. S_n is the individual component surface area. τ_n is the individual component sound transmission coefficient. With the frame transmission loss calculated based on experimental data and the glass performance calculated by theoretical model, the overall window element transmission loss is easy to obtain by using the area-weighted logarithmic average of individual components.

The measurements were divided into two categories: one in which only the unframed infills were tested, and the other one has the same kind of infills tested inside an inward opening Aluminum window frame.

2.1 Test Environment

The experiments in this paper were performed by Riverbank Acoustical Laboratories™ (RAL) by ASTM E90 – 09(2016) "Standard Test Method for Laboratory Measurement of Airborne Sound Transmission Loss of Building Partitions and Elements." There are three testing chambers in RAL that can be used as either source room or receiving room. The volume of chamber1, chamber2, and chamber3 were 177 m^3, 178.3 m^3 and 131.3m^3, respectively. An air gap structurally and vibrationally isolated each of the two adjacent rooms. In the tests, all specimens were placed at the edge of the receiving chamber. Rotating microphones obtained space and time-averaged sound pressure levels, and these values were measured to calculate the transmission loss(TL) in 1/3 Octave bands from 50 Hz to 5000 Hz.

2.2 Type of Test Samples

The unframed infills tests used Chamber 2 as the source room and Chamber 3 as the receiving room. Chamber 3 has a dimension of 6.11m x 4.27m x 5.04m. The filler wall between two chambers was built with solid cast concrete. The tested opening for unframed infill was 1045mm x 1294mm. Three different glass and one composite mask were tested in this group. Table 1 shows the measured composition of each infill type. The glass specimen tested for this study were all manufactured by Viracon.

For the frame performance study, one kind of typical Aluminum window frame was used for all framed infill tests. The tests in this category used Chamber 1 as the source room and Chamber 2 as the receiving room. Chamber 2 has a dimension of 7.14m x 5.18m x 4.56m. The filler wall was constructed using multi-layered gypsum board with a measured STC value of 61. The tested opening for framed infill is 1230mm x 1480mm.

Table 1 – Composition detail of the unframed infills

No.	Glass Details	STC
1	13.1mm Glass(1.52mm PVB), 19.1mm Air space, 7.4mm Glass (0.76mm PVB)	42
2	9.5mm Glass, 18.4mm Air space, 3.9mm Glass	39
3	5.7mm Glass, 13.7mm Argon, 5.8mm Glass	33
4	Composite Mask	52

2.3 Mask Composite

In testing aluminum profiles it is crucial to have a setup that can ensure the only significant sound transmission path was through the tested aluminum frame. There are some criteria that was follow when designing the masking technique. Firstly, the surface of the mask panel needs to be aligned with the surface of the frame to avoid grazing incidence on the mask edge. Secondly, for geometry reasons, only a limited frame depth is available to hold the mask panels, the mask composition needs to choose the material with high density and ideally good damping capability.

Table 2 – Composite mask construction detail from source room to receive room

Composition	Thickness(mm)	Weight(kg)
Steel plate	3.10	32.32
Mass Loaded Vinyl sheet	3.18	7.49
Glass No. 1	39.69	64.18
Gypsum board	15.88	13.27
Mass Loaded Vinyl sheet	6.63	13.38
Steel plate	3.10	32.32
Gypsum board	15.88	13.27

In the setup, the mask panel consists of two layers of 3.1mm thick steel plate to guarantee high area mass. In between these steel layers, two layers of the mass loaded vinyl sheet is included to improve damping effect, and the remaining space are filled with gypsum board. The construction sequence of the composite mask is explained in Table 2. The area density of the composite mask reached a high number of 130kg/m^2. Figure 1 shows the photo of mask setup and 3D rending for the exploded view of the composite mask design. The drawing details is presented in Figure 2. The masking panels constructed have the exact size of the window frame's daylight opening size, and the panels are fastening into the frame through a friction fit. The edges of the mask are well-sealed with acoustic caulk and duct tape.

Figure 1 - (left) A Photograph of the masked window (right) Exploded view of the masked window

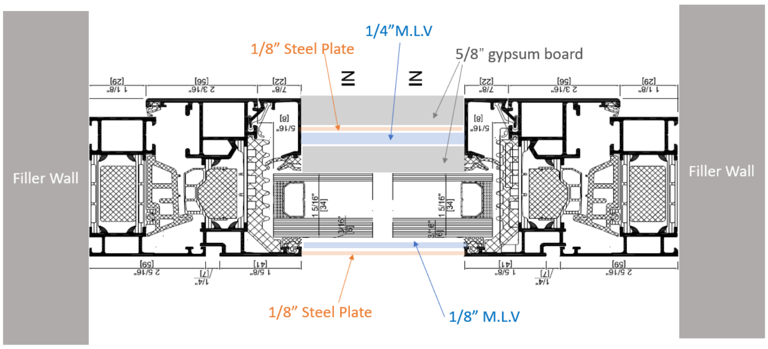


Figure 2 - Drawing detail of the masked window

3. RESULTS and DISCUSSIONS

3.1 Framed Glass vs. Unframed Glass

Figure 3 - 5 compares the unframed glass and the framed glass for three different test cases. The glazing composition for glass No.1 - 3 is shown in Table 1. Their sound transmission behavior differs in different frequency ranges; the resonance frequency and coincidence frequency for each glass sample are marked in the chart.

In the frequency range below 100Hz, the measurements do not follow a clear pattern as the data collected is greatly affected by the testing environment. In the frequency range above 100Hz, the test data is reliable. The main reason is that the Chamber 2 and Chamber 3 are relatively large as receiving chambers, and thus they all give very low fundamental frequencies. The eigenfrequencies of the test chambers can be calculated by

$$f_{nmp} = \frac{c}{2} \cdot \sqrt{\frac{n^2}{L^2} + \frac{m^3}{B^2} + \frac{p^2}{H^2}} \qquad (1)$$

where L, B, and H are length, width and height of the room, c is the sound speed in air and n, m and p represent the order of room modes corresponding to L, B, and H, respectively. The analytically solved first eigenfrequencies for the receiving chambers are below 40Hz. As a result, the test chamber effect is negligible in a higher frequency range. Also, the 95% confidence interval of the experimental results at a frequency higher than 100Hz is less than ±1dB, which suggests a stable testing result with this frequency range.

For frequency range between100Hz and the double layer glass resonance frequency, the inclusion of the Aluminum frame decreased the glass TL by 0dB ~ 4dB. The reduction was expected, as the aluminum frame vibration may deliver the sound power to the glass panels through the glass edges.

At higher frequencies, the double panel glass model can be simplified to a model of two limp mass coupled by a spring(1). The mass-air-mass frequency is derived assuming the only normal incidence excites the partition, the equation obtained is:

$$f_r = \frac{c}{2\pi} \cdot \sqrt{\frac{\rho_0}{d} \cdot \left(\frac{1}{m_1} + \frac{1}{m_2}\right)} \qquad (2)$$

where m_1 and m_2 are the surface densities, ρ_0 is the air density, d is the spacing between two panels. In Figure 3 and 4, it is noticeable that for the two double insulating glass specimens of glass No.2 and glass No.3, the framed glass and unframed glass both have a dip in the calculated glass resonance frequency. However, for the double laminated glass No.1, the same dip at the glass resonance frequency did not occur. Figure 5 presents the glass No.1 transmission loss curve comparison between the published data from the manufacture and the measurements taken in this study. The manufacture specimen size was 2.1336m x 0.9144m. The data from the manufacture shows a clear dip in resonance frequency. As the specimen in RAL was held in the test opening by dense mastic around the perimeter, the extra damping at the specimen edges reduces the resonance amplitude and is likely responsible for the missing dip.

Above the resonance frequency, the framed glass shows close performance to the unframed glass for double insulating glass; in this region, the sound behavior is mainly based upon the total mass of the sample. In the higher frequency range, the two panels act individually. For every single plate, the coincidence frequency is given by:

$$f_c = \frac{c^2}{2\pi} \cdot \sqrt{\frac{m}{B}} \tag{3}$$

where B is the bending stiffness, m is the surface density of the calculated plate. Again, framed glass TL curve shows a dip at the same frequency of the unframed glass critical frequency. A larger difference between unframed glass and framed glass TL are found at frequencies above the critical frequency.

In all three tests, the single number ratings of the framed glass closely reached the unframed glass ratings, the same holds for the high sound insulation glass with a measured STC value of 42dB. The STC of framed glass No.3 and the OITC value of framed glass No. 1 are even 1dB higher than those of the unframed glass tests. The observation is in line with previous studies on Aluminum window frame(2, 3). Hence, it can be concluded that, with proper design and sealant, even though Aluminum frame was full of cavities and extruded in thin wall thickness, it can achieve high sound reduction for the overall window systems together with good performance glass.

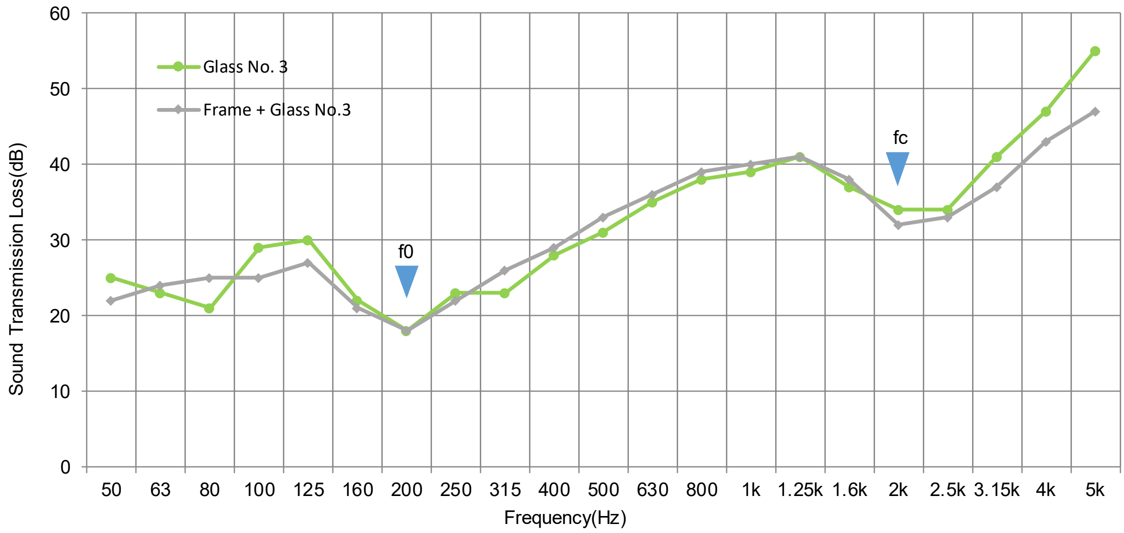


Figure 3 - STL of unframed and framed double insulating glass No. 3

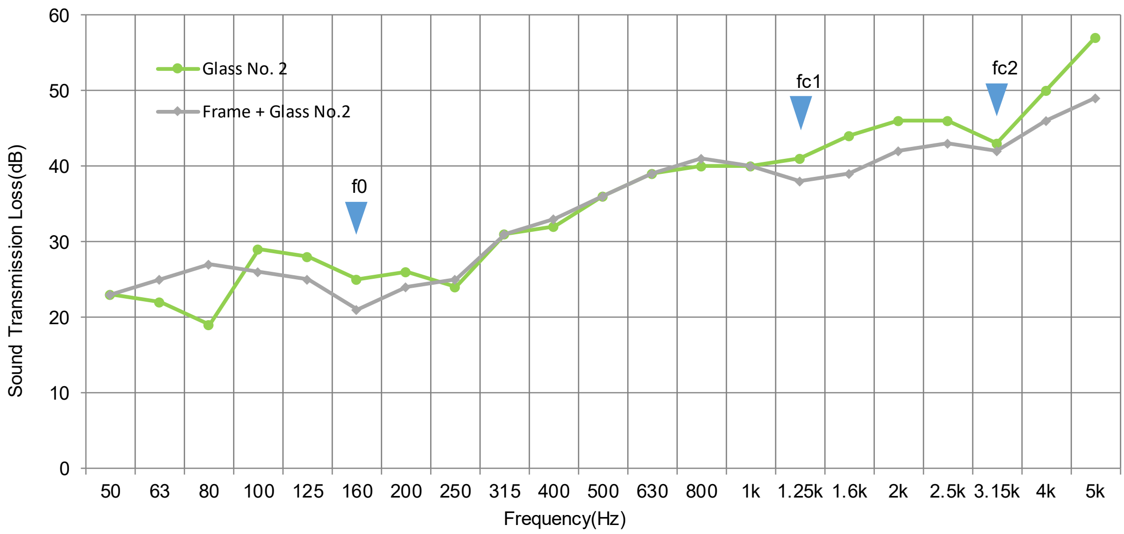


Figure 4 - STL of unframed and framed double insulating glass No. 2

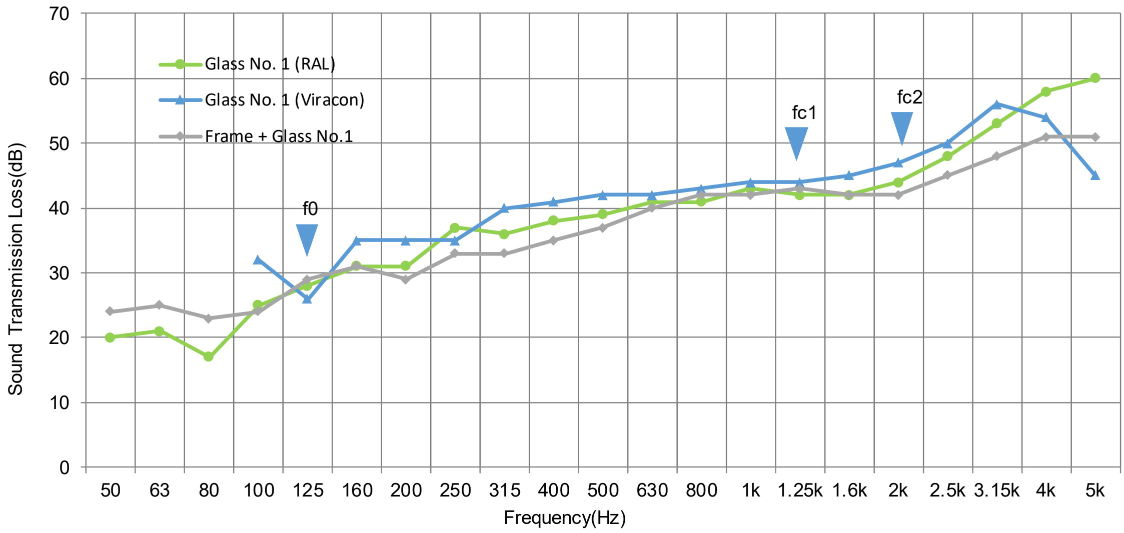


Figure 5 - STL of unframed and framed double laminated glass No. 1

3.2 Masking Procedure

The fundamental idea of the masking procedure design is built up a heavy mass shield to block the incident airborne sound power path in the window vision area, only leave the frame area as the primary path for sound energy transmission. Using the result of the mask only test and framed mask test, the acoustic properties of the frame can be extracted using Eq (4).

As the window and façade element consists of frame components and infill component, the logarithmic average equation becomes:

$$R_{total} = -10\,log_{10}\left(\frac{1}{S_{frame} + S_{infill}} \times (S_{frame}\tau_{frame} + S_{infill}\tau_{infill})\right) \qquad (4)$$

where R_{total} is the framed mask transmission loss, S_{frame} is the frame surface area, S_{infill} is the infill surface area, τ_{frame} is the frame sound transmission coefficient and τ_{infill} is the frame sound transmission coefficient.

The calculated Aluminum frame transmission loss using masking procedure can be found in Figure 6. Comparing the tested mask TL and calculated frame TL, the sound power transmitted through the mask composite is more than 10dB in all frequencies range except at 100Hz, 125Hz, and 160Hz. It can be further observed that the TL of the composite mask shows an increasing linear trend above 200Hz, which indicates a mass-controlled behavior and no flanking transmission concern around the sample perimeter. Thus, it is reasonable to assume that, in a framed mask test, most of the sound energy passes through the aluminum frame.

The STC/OITC value of the composite mask is 52/44dB. In the condition that the masking procedure is difficult to conduct, a high sound insulation glass can be used as the masking shield if the single number rating of the glass is close to the composite mask. Using high-performance glass as the shield, it ensures a more comparable boundary behavior and sealing condition. As in most designs, the frame and glass connection mechanism is consistent for the same aluminum frame product line, and the glass is likely to be installed to the Aluminum frame through a gasket made of EPDM or structural silicone.

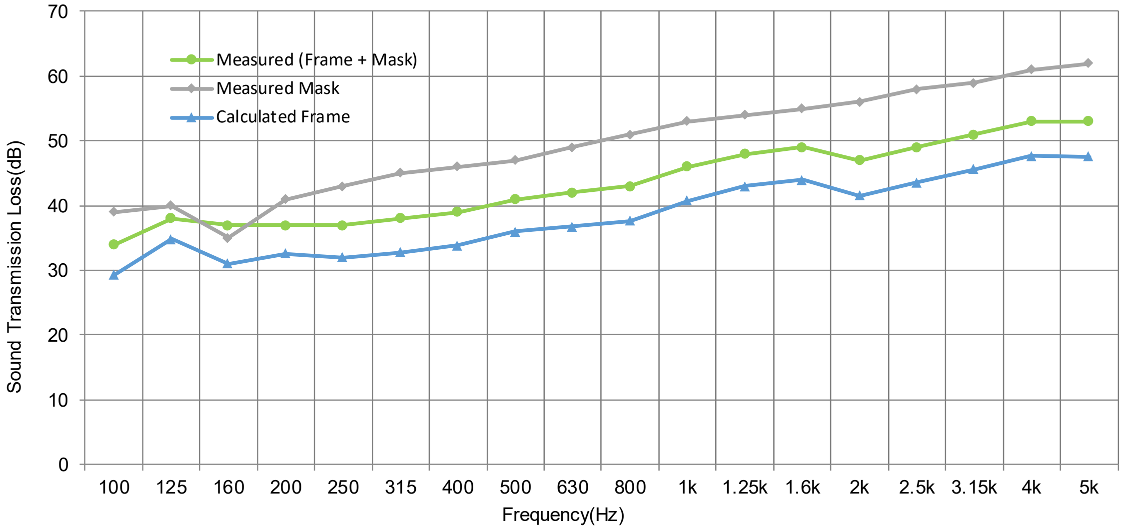
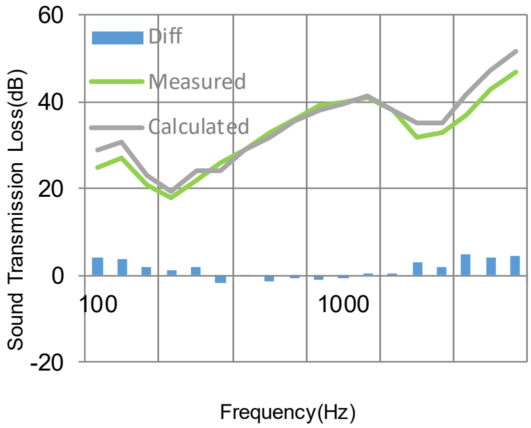


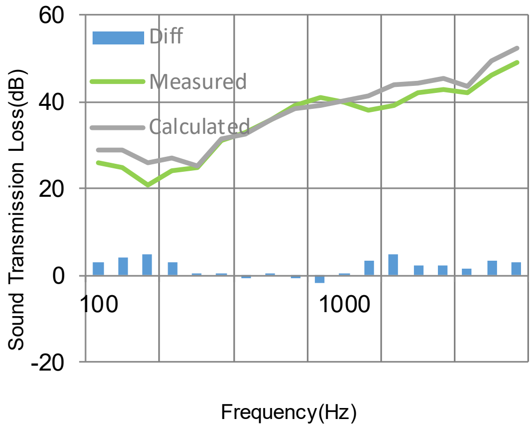
Figure 6 - STL of measured framed mask system, unframed mask composite, and calculated frame results

3.3 Validation

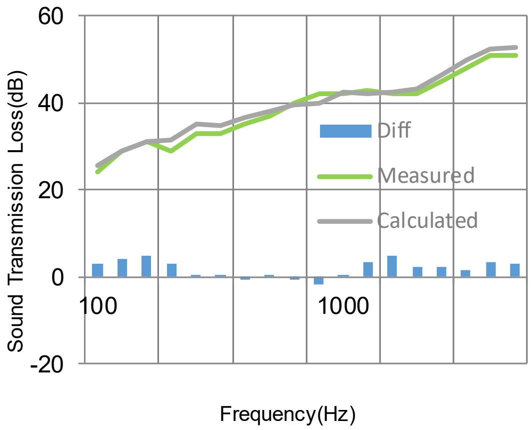
Figure 7 presents four validation cases for the masking procedure; A good agreement can be seen for the general trend between the measured and predicted window element performance. The prediction method also gives a good estimation of the single number rating within ±1dB (see Table 3).



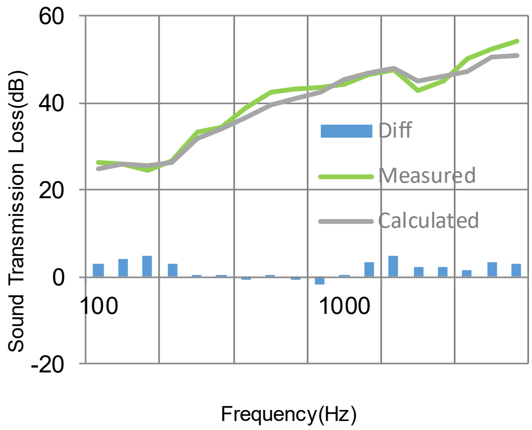
(a) Glass No.3



(b) Glass No.2



(c) Glass No.1



(d) Glass No.4 - 8mm/20mm/6mm

Figure 7 - STL comparison of measured and predicted window results of four different glass options

Table 3. Single number rating comparison of measured and predicted results

	Glass No.1		Glass No.2		Glass No.3		Glass No.4	
	STC	OITC	STC	OITC	STC	OITC	STC	OITC
Measured unframed glass	42	33	39	31	33	28	43	33
Measured framed glass	41	34	38	31	34	28	42	34
Predicted framed glass	41	35	39	32	34	29	42	34

It is worth mentioning that the comparison data in Figure 7(d) were gathered from the ift Rosenheim testing lab at various times over all the years, but still achieved a good comparison trend. The glass composition is 8mm clear glass with 0.76mm acoustic PVB interlayer, 20mm argon space, and 6mm clear glass.

Although the prediction method shows good agreement with the experiment results, this method shall not be treated as a replacement to the laboratory test; it could serve as a quick and relatively accurate sound performance analysis method in building pre-construction phase.

4. CONCLUSIONS

This study focused on the sound behavior of the Aluminum frame in window systems. A series of unframed and framed glass tests were conducted to study the acoustical effect of inclusion of Aluminum frame as the window perimeter.

Also, a masking procedure to obtain the frame sound performance is proposed. The frame performance can then be combined with the glass TL estimation to get the entire window or façade STL. Once the frame STL is obtained, and the glass STL estimated through experiments or theoretical model, the window element sound properties can be calculated using Eq(5). An accurate glass estimation method for double insulating glass and double laminated glass has been proposed in another work from the second co-author of this paper(4).

As a conclusion, the idea of the masking method would be an effective and economical approach to identify the aluminum window and façade element sound characteristics.

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