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PREDICTING ACOUSTIC PERFORMANCE OF WINDOWS WITH HIGH SOUND INSULATION

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ABSTRACT

Maintaining the acoustic comfort of people in buildings is an issue of great importance today. The sound insulation of the building envelope, including windows, is a very important factor for indoor noise for buildings placed in cities and near roads, airports, or industrial plants. Based on Annex B of EN 14351-1, window manufacturers can predict and declare the weighted sound reduction index (R_w) of a single window based on the known weighted sound reduction index of the glazing, but only if the target R_w is less or equal to 38 dB. The ability to design a window with a higher insulation value is highly desirable for window manufacturers. In this article, we present the results of a study to determine the contribution of glazing and window frame insulation to the final window R_w result. Laser vibrometer tests of the window and finite element method (FEM) simulations were carried out to determine the insulation performance of the frame.

Keywords: *windows insulation, FEM, vibrations, sound reduction index*

1. INTRODUCTION

Nowadays, external noise in cities is increasing and its impact on residents is increasingly detrimental. Modern architecture is moving towards designing exterior walls with ever-larger windows, making their impact on the acoustic comfort inside a building crucial. Designing and manufacturing windows with a high acoustic insulation value while taking into account other parameters is becoming increasingly challenging. To meet the needs of window manufacturers, engineers are attempting to simulate the acoustic insulation of windows.
The effect of glazing on window insulation is well known and studied [1,2]. The significant impact of installing glazing in a window frame is well known [3,4]. The effect of the window vents on the sound insulation value was assessed using both measurement [5] and simulation methods [6]. The need for windows and high insulation is being addressed, and attempts are being made to improve the insulation of existing windows by improving airtight of the frame [7] and using additional absorbing materials [8]. A comparison was also carried out between simulated and measured sound insulation values for double-glazed windows with absorbing material between the panes. [9]. The influence of the insulation and the design of the window frame on the insulation of the window was also examined [10]. Neural networks trained with the results of multiple measurements were also used to predict window insulation with satisfactory accuracy [11].
The topic of assessing the insulation performance of windows, in particular the high R_w values, needs to be developed and advanced test methods sought. In this paper, an attempt is made to combine the results of sound insulation measurements by classical methods [12], with vibration measurements and acoustic modelling, in order to determine the contribution of the glazing and frame to the final sound insulation value of the window.
Standards ISO TS 7849-1 and ISO TS 7849-2 describe the methods to evaluate the radiated sound power based on vibration measurements [13,14]. Note, that a hybrid vibroacoustic method of measuring sound insulation can be implemented if one combines the vibration-derived radiated acoustic power with the incident acoustic power evaluated

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from acoustic measurements. The advantage of utilizing vibrational measurements in sound insulation determination is the capability of showing the spatial distribution of energy radiated by the partition. There are also available methods based purely on vibrational data, but they were proven to be effective only at low frequencies, and require more effort in conducting experiments [15].

In our research, we investigate the capabilities of mentioned hybrid (vibroacoustic) method in predicting the acoustic performance of windows with high sound insulation. We employ a semi-empirical approach, where the experimental part of the method consists of utilizing a laser vibrometer to determine the vibration velocities from the receiver side and measuring acoustic response in the source chamber. The FEM simulation part consists of evaluating the sound radiation efficiency (also called the radiation factor) of the glazing and the frame. This is in contrast to standard ISO TS 7849-2, which recommends performing time-consuming experiments to determine the ensemble-averaged radiation factor. Finally, we compare the obtained transmission loss (TL) results with conventional sound insulation measurement results (pressure method) [12].

2. METHODOLOGY

Measurements and simulations were carried out at ARIC (Acoustics Research and Innovation Center) run by KFB Acoustics in Poland.

Figure 1. Two sets of reverberation chambers for isolation measurements at ARIC.

2.1 Sound insulation measurements using the pressure method (conventional measurements)

To determine the assigned value measurements of the window sound insulation were taken in accordance with EN ISO 10140-2 [12]. The test specimen was installed in the measurement opening. White noise was emitted in the source room. The sound pressure level in the source and receiving room was measured and the sound insulation in 1/3 octave bands was calculated based on the formula:

$$R_w = L_1 - L_2 + 10\, lg\, \frac{S}{A} \tag{1}$$

where L_1 is sound pressure level in source room [dB], L_2 is sound pressure level in receiving room [dB], S is are of test specimen [m^2] and A is equivalent sound absorption area in receiving room [m^2].

A single-number assessment was also carried out in accordance with EN-ISO-717-1 [16].

Figure 2. Reverberation room set V1 interior during sound insulation measurements.

2.2 Determination of sound insulation by hybrid method

To obtain a sound reduction index R by a hybrid method, the following steps were followed. Incident acoustic power was calculated by using the equation:

$$\Pi_e = S\,\frac{\overline{p_e^2}}{4\rho c} \tag{2}$$

where $\overline{p_e^2}$ is the spatially averaged mean-square sound pressure in the diffuse field, S is the surface area of the partition, ρ is air density and c is sound speed in air.

On the other hand, radiated acoustic power is equal to:

$$\Pi_r = S\rho c \sigma \overline{v_r^2} \quad (3)$$

where $\overline{v_r^2}$ is the mean-square vibration velocity of the structure and σ is the radiation factor (in this paper determined by FEM).
Finally, the sound reduction index R was computed by taking the ratio of incident and radiated power:

$$R = 10 \log\left(\frac{\Pi_s}{\Pi_r}\right) \quad (4)$$

In order to obtain the radiation factor σ from equation (3), an FEM simulation was conducted. A virtual prototype of the window resembling the real geometry and material parameters was built in Comsol Multiphysics software. The model included fluid-structure interaction, so that both the simulated mean-square velocity $\overline{v_{r,s}^2}$ and the simulated radiated power $\Pi_{r,s}$ could be obtained. The free-field radiation conditions were obtained by utilizing PML (Perfectly Matched Layers). Finally, σ was obtained by rearranging the equation (3) and replacing $\overline{v_r^2}$ with $\overline{v_{r,s}^2}$ and Π_r with $\Pi_{r,s}$:

$$\sigma = \frac{\Pi_{r,s}}{S\rho c\, \overline{v_{r,s}^2}} \quad (5)$$

2.2.1 FEM simulation to determine radiation efficiency

The geometry of the window was built considering a frame and two sheets of glass. To determine the radiated sound power, it was necessary to create an acoustic domain.
Four types of materials were defined for the numerical model. Polyethylene, glass, argon between the glass sheets and air for the acoustic domain. In addition, three different physics were used in COMSOL (solid, shell and pressure acoustic), in addition to the coupling of these physics.

To calculate the radiation efficiency, it was necessary to calculate the velocity of vibration of the frame and the glass and then calculate the average radiated sound power on the surface of the hemi-sphere as can be seen in Figure 3.

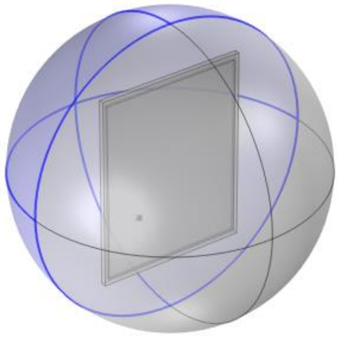

Figure 3. FEM model geometry of test specimen.

2.2.2 Laser vibrometer tests

Measurements with the laser vibrometer were made on a specimen mounted in the reverberation room assembly as in conventional acoustic measurements. From the side of the source chamber, the sample was excited using a loudspeaker emitting a wide-band noise.

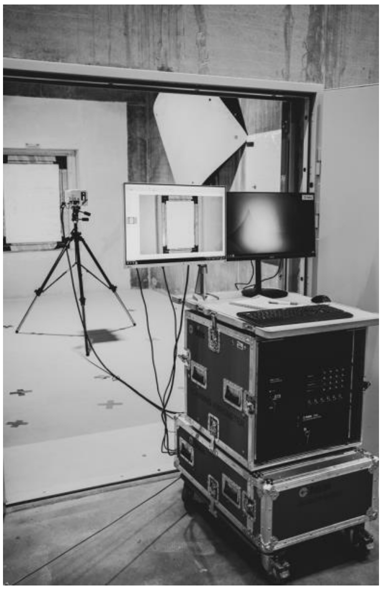

Figure 4. Laser vibrometer set.

Measurements were taken of the vibrations of the glazing and individual window frame components. Examples of vibration visualizations are showed in Figures 5-7.

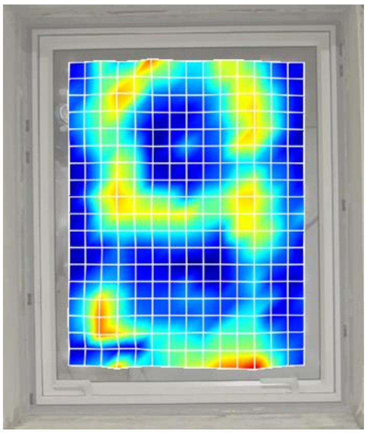

Figure 5. Vibrations of glazing visualization (200 Hz resonance mode).

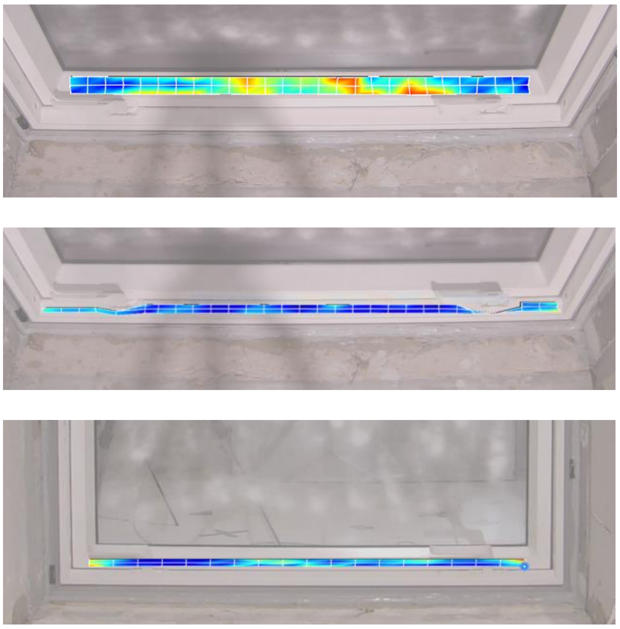

Figure 6. Vibrations of part of the frame visualization.

Figure 7. Vibrations of part of the frame visualization.

3. TEST SPECIMEN

The test object was a 1080 mm x 1330 mm double-glazed roof window with PVC frame.

4. RESULTS

4.1 Sound reduction index for whole test specimen

Figure 8 shows comparison between the sound transmission loss of the window obtained by the conventional and the hybrid method.
In hybrid method different values of σ was used. There was an overestimation of TL above 1.25 kHz and underestimation for lower bands when σ=1 was assumed for both frame and glazing (A). The result given by introducing σ of glazing simulated by using FEM gives big overestimation for bands below 200 Hz and underestimation for band above 1.6 kHz(B). Conventional measurements are marked as C.

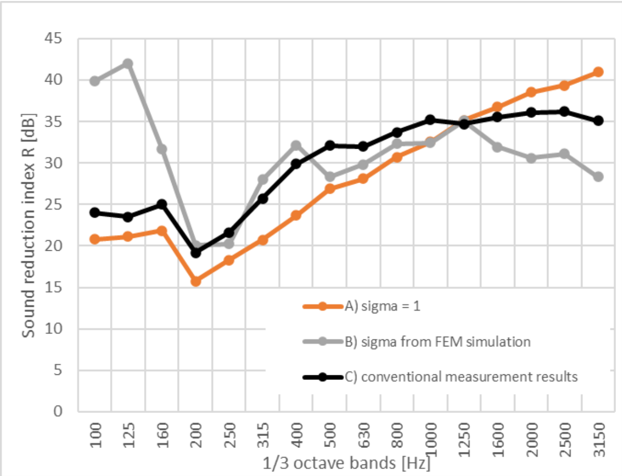

Figure 8. Comparison of insulation by different methods.

Weighted sound reduction index R_w ($C;C_{tr}$) is given as follows:

A) Sigma = 1 R_w = 30 (-1;-4)
B) Sigma from FEM R_w = 31 (-1;-2)
C) Conventional measurement R_w = 33 (-1;-3)

4.2 Insulation contribution of glazing and frame

Based on the hybrid method, the sound insulation contribution of the glazing and the window frame was determined.
Figures 9 and 10 show the simulation results of the insulation distribution for sigma = 1 (Figure 9) and sigma calculated from the FEM simulation (Figure 10).

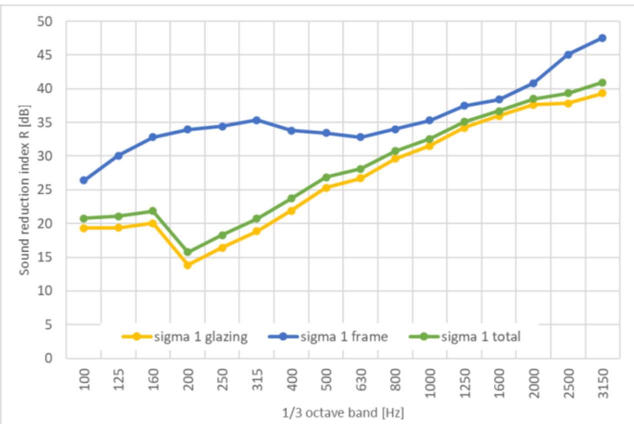

Figure 9. Contribution of sound insulation for sigma = 1.

Weighted sound reduction index R_w ($C;C_{tr}$) for sigma =1 is given as follows:

- Glazing R_w = 29 (-1;-5)
- Frame R_w = 37 (0;-2)
- TOTAL R_w = 30 (-1;-4)

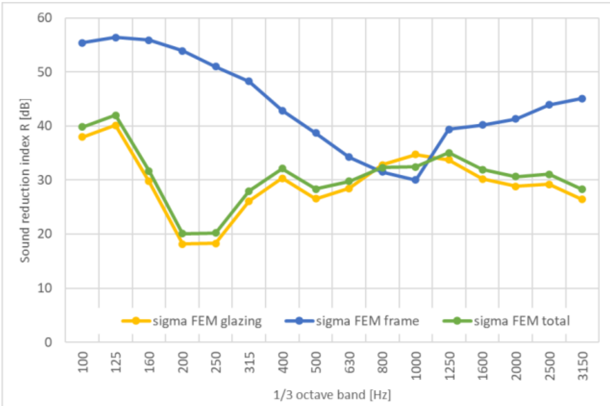

Figure 10. Contribution of sound insulation for sigma from FEM.

Weighted sound reduction index R_w ($C;C_{tr}$) for sigma from FEM is given as follows:

- Glazing R_w = 29 (-1;-1)
- Frame R_w = 38 (-2;-3)
- TOTAL R_w = 35 (0;0)

5. SUMMARY

The results of the window insulation measurements show the potential of the proposed hybrid method in quickly determining the contribution of the frame and glazing to the total sound insulation of the window.
Further research is planned to increase the accuracy of the determined insulation values. The results of the study show that to obtain more satisfactory results, the radiation efficiency values of the window elements (sigma) need to be made more realistic. To achieve this, it is planned to use the vibration velocity values obtained from the laser vibrometer measurements to create a more accurate FEM model.
As a further step, it is planned to verify the method on a larger number of samples.

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