Numerical Modelling of Sound Transmission Through the Window Type Partition

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Abstract

The approach to numerical modelling of sound transmission through window type partitions is investigated in the paper. The laboratory conditions of reverberation room are simulated. The numerical and experimental results are compared. The impact of different model parameters on the sound insulation levels are evaluated.

Keywords: sound transmission, acoustic insulation, window, numerical simulation

1. Introduction

There are several basic approaches to sound insulating: increasing the distance between source and receiver, using noise barriers to reflect or absorb the energy of the sound waves, using damping structures such as sound baffles, or using active antinoise sound generators. Those approaches are implemented through a variety of techniques: vibration isolation, sound insulation, sound absorption and vibration damping. The window type partition is primarily a mass barrier with sound insulation properties.

There were several attempts to simulate sound insulation properties of partitions numerically. In the literature, this type of problems are usually referred to as vibroacoustic or structural-acoustic effects with fluid interaction. Davidson [1] investigated structure-acoustic effect, which involved a flexible structure coupled to an enclosed acoustic fluid. Ruber et al. [2] have investigated of a tuned vibration absorber with high damping for increasing acoustic panels sound transmission loss in low frequency range. Sakuma et al. [3] performed a numerical investigation of the niche effect in sound insulation measurement. Their numerical results demonstrate that sound reduction index decreases below the critical coincidence frequency due to niches, while it increases above the frequency. It was also confirmed that the effect of the two sided niche with a centrally located specimen is largest at low frequencies.

Dimino et al. [4] investigated a vibroacoustic design of an aircraft-type active window. An experimental modal analysis was carried out to determine both single partition and coupled fluid-structure modal frequencies used to validate the finite element model. The sound radiation characteristics of the window prototype via numerical procedure of coupling boundary and finite element methods was proposed to solve the coupled acoustic structure problem in the exterior acoustic domain. The above publications did not considered the standardised sound insulation measurement procedure, therefore the obtained results were difficult to be compared comprehensively.

Gimeno [5] studied the acoustic insulation of domestic windows, with the objective to compare the experimental and numerical methods. The calculations were made in COMSOL. Obtained results were not completely satisfactory, due to 2D numerical model restrictions and certain differences in boundary conditions between the numerical model and experimental measurements.

In this paper, a 3D approach to numerical modelling of sound transmission through a domestic windows, based on laboratory measurement standardised procedure EN ISO 20140-3, was investigated.

2. Laboratory measurements

The airborne sound insulation of domestic windows can be evaluated from laboratory measurements of the sound reduction index according to EN ISO 20140-3 norm [6]. The results acquired in laboratory can be used to compare the properties of sound insulation of building elements, to classify such items according to their capabilities of acoustic insulation, help design building products which require certain acoustic properties and estimate the in situ performance in complete buildings. The measurements are performed in laboratories in which sound transmission via flanking paths is suppressed. However, the results of measurements made in accordance with this standard cannot be applied directly to the field situation without accounting for other factors, such as flanking transmission, boundary conditions and total loss factor. The laboratory measurements are made using octave or one-third-octave bands.

The airborne sound insulation measurement, known as the reverberation room method, takes into consideration two chambers: a source chamber and a receiving chamber separated by a test element. It is assumed that all sound is transmitted via the test element, and that the structure of the transmission suite itself plays no role other than defining the space for the source and receiving rooms.

The transition coefficient τ, is defined as the ratio of the sound power transmitted by the test element W_2, to the sound power of the source W_1, expressed in Watts:

$$\tau = \left(\frac{W_2}{W_1}\right) \tag{1}$$

The sound reduction index R expressed in decibels is the inverse of the wall's transmission factor. In the laboratory measurements the index R is determined by measuring sound pressure level L_1 and L_2 in the two rooms. The following is obtained [6]:

$$R = L_1 - L_2 + 10\log\frac{S}{A} \quad \text{(dB)} \tag{2}$$

Where: L_1 is the average sound pressure level in the source chamber (dB),
L_2 is the average sound pressure level in the receive chamber (dB),

S is the test area (m^2),

A is the equivalent sound absorption area in the receiver chamber (m^2).

Dijckmans and Vermeir [7], carried out an extensive parametric study with a wave based model to numerically investigate the fundamental repeatability and reproducibility in such acoustical measurements through the different partitions. The effect on the uncertainty of single number quantities by including low frequencies (50-80 Hz) was discussed. Furthermore, their parametric study gave information to what extent it is possible to predict the sound insulation by laboratory results. In the low-frequency range, the sound transmission level as measured in the laboratory was not representative for results *in situ*. The same partition can give different sound transmission values, depending on the geometry and dimensions of the chambers or the partition. This source of uncertainty should be taken into further consideration.

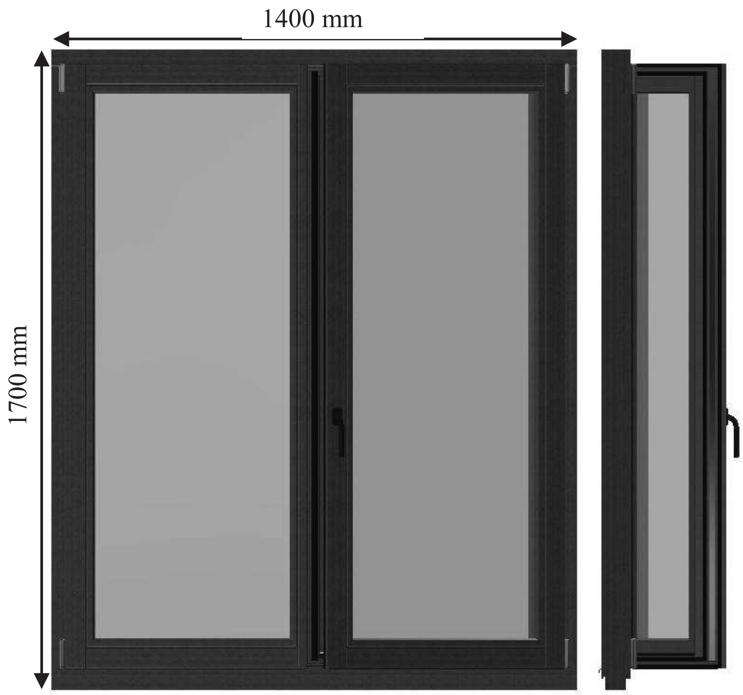

Figure 1. The CAD model of analysed window

The window frame (Figure 1), analysed in *Ship Design and Research Centre CTO*, has overall dimensions of . The default frame thickness 'G' is 78 mm and default frame height 'H' is 98 mm. The width of the central pillar is 82 mm. The default frame material is Meranti wood with density of 800 kg/m^3 and sound speed of 4500 m/s. The window glass material has density of 2500 kg/m^3 and sound speed of 5580 m/s. Three types of glazing where installed and measured: 4/12/4/12/4, 8/12/4/12/6 and 4/16/4. Every odd number in the sequence defines the glass thickness in mm, while every even number defines the distance in mm between subsequent glasses. The laboratory measurement results were discussed and compared further in section 4.

3. Numeric model

The window frame with three glazing types from laboratory measurements were modelled and enclosed in calculation space created in ANSYS Workbench environment, bisecting it into source and receiving domains. As the considered window has two planes of symmetry, the calculation space was restricted to 1/4 of the window (Figure 2). Using the symmetric boundary conditions significantly reduced the computational cost of the model, giving the results for whole window.

The introduced calculation space boundary condition is the wall that is around the model. Perfectly Matched Layer (PML) is utilised to obtain an absorption condition. Acoustic Mass Source with amplitude of 0.01 kg/m^{2}s is located at rear wall of source domain, ensuring a parallel wave excitation as required in [6].

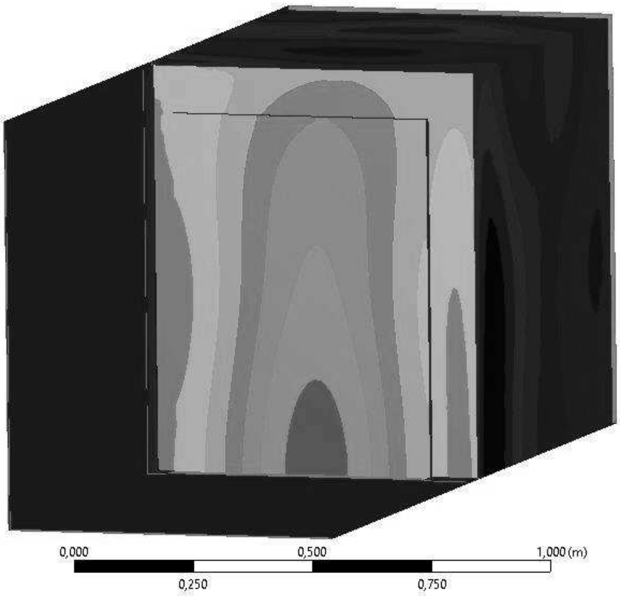

Figure 2. The calculation space with sound pressure level results for 500 Hz excitation

The frequencies of interest were those between 50Hz and 5000Hz, influence the mesh size (Figure 3): at least five elements should be used to model the shortest wavelength (0,06806 m at 5000 Hz), therefore size of the element is assumed to be 0,01 m. The assumed FE size was next validated by comparing with higher density meshes. The ANSYS FLUID 220, a higher order 3-D 20-node solid element that exhibits quadratic pressure behaviour, was used in the analysis (for more details see ANSYS online help documentation).

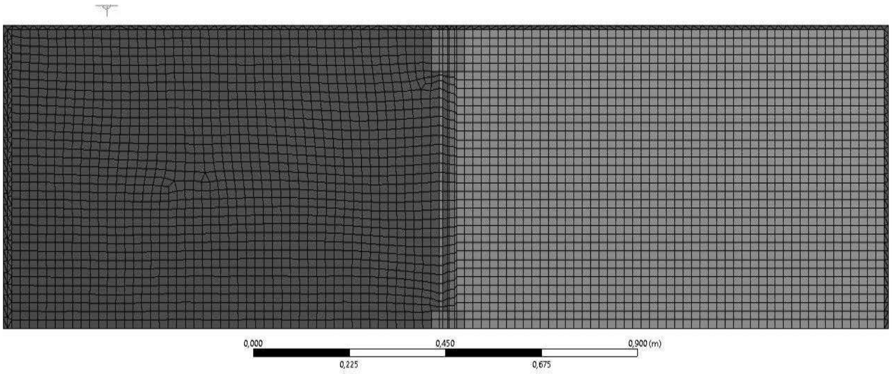

Figure 3. Geometry of the model (half-bottom view) and finite element size

In the numerical calculations, the sound reduction index R is defined as [6]:

$$R = 10\log\frac{W_1}{W_2} \quad \text{(dB)} \tag{3}$$

Where the W_1 is sound power calculated in the source domain and the W_2 is the sound power calculated in receiver domain. The sound power in the model was determined by setting up ANSYS acoustic power monitors in both domains. This approach, (acoustic power instead of acoustic pressure in the laboratory measurements [6]), allows to reduce dimensions of the source and receiver domains to minimum.

4. Numerical results

An Acoustic Harmonic Analysis in ANSYS Workbench environment was conducted. The experimental and numerical results were calculated in one-third-octave band (21 frequencies in range between 50 and 5000 Hz), however the reference glazing manufacturer data results were given in octave bands in range 125 to 4000 Hz (6 frequency values represented in the below diagrams in solid black). When comparing measured data, care must be taken to differentiate between measured data for glazing and measured data for windows. The reason is that the overall sound insulation performance of a window is affected by the window frame and the sealing of the glazing. The variety of measurement results acquired in CTO laboratories caused by sealing differentiation is represented on the diagrams below by group of the same-coloured lines.

Figure 4 represents the comparison between the group of six experimental measurements for glazing 4/12/4/12/4 with different sealing configurations – "CTO 444" (grey) – and the numerical results "ANSYS 444". The visible difference for the low frequencies between (50-80 Hz) may occur due to measurement uncertainties described in [7]. Even if it was possible to measure the source and transmitted intensity correctly, the problem of reproducibility at low frequencies remains. The theoretical sound reduction index R - defined as the ratio between source and transmitted sound power - is also influenced by all the parameters which determine the modal composition of the sound fields and the modal coupling. One way to reduce the variations in low-frequency measurements is the use of more octave band values. As more modes are present in an octave band, variations in the sound transition values should be smaller [7]. The another significant difference was observed for 3200 and 5000 Hz frequencies probably due to the fact that measurements do not account for indirect transmissions and loss factor effects.

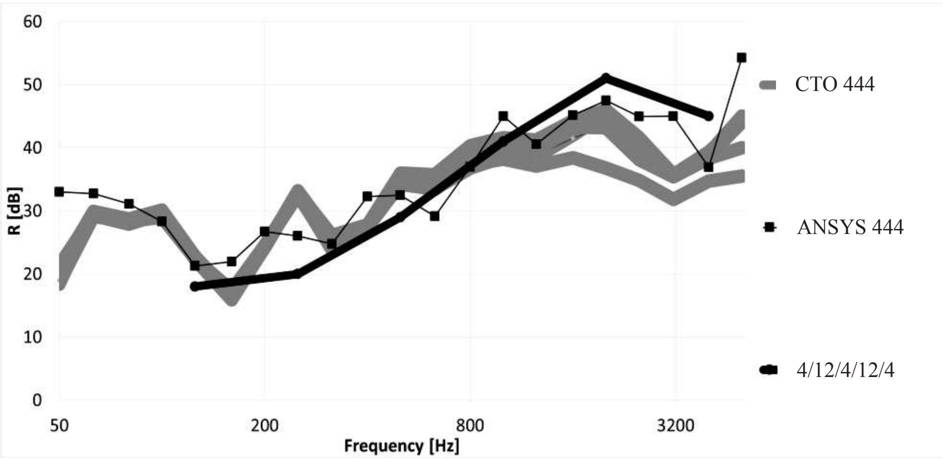

Figure 4. The comparison of numerical ANSYS 444 and experimental CTO 444 results for 4/12/4/12/4 type of window glazing

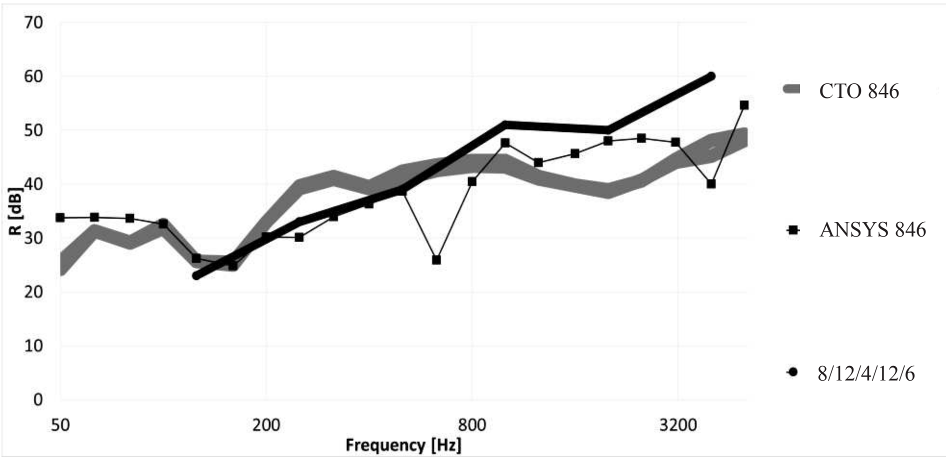

Figure 5. The comparison of numerical ANSYS 846 and experimental CTO 846 results for 8/12/4/12/6 type of window glazing

Figure 5 represents the comparison between two experimental measurements for 8/12/4/12/6 glazing with different sealing configurations – "CTO 846" (grey) – and the numerical results "ANSYS 846". The same, low frequency differences can be observed.

The significant difference at 630 Hz most probably occur due to the coincidence effect. The discrepancies in the range between 200-400 Hz and 1250-3150 Hz were associated with seals.

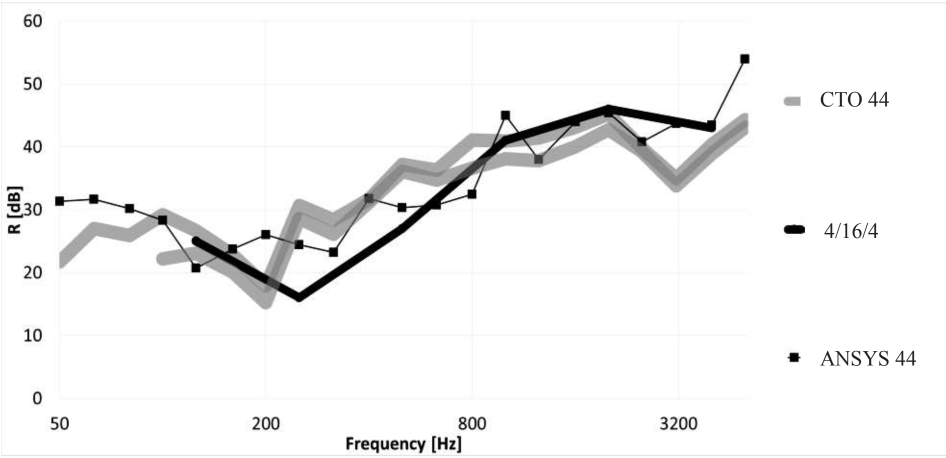

Figure 6. The comparison of numerical ANSYS 44 and experimental CTO 44 results for 4/16/4 type of window glazing

Figure 6 represents the comparison between two experimental measurements for different glazing sealing configuration – „CTO 44" (grey) – and the numerical results „ANSYS 44". Once again, the low frequency differences can be observed. As the different window models were studied, we may conclude that although the experimental and numerical results follow similar pattern, there were not exactly the same. There are several possible reasons for that.

The reverberation room method for measuring sound insulation performance of glazing and window type partitions involves the "niche effect" as a bias error factor [3]. It is known that the niche effect occurs when a specimen is mounted inside an aperture in the common wall between two chambers, and the dependence of the measured transmission loss on the specimen position in the aperture is not negligible. This effect is difficult to account for in experiment as well as in numerical calculations. A vibroacoustic coupling analysis should be employed in the future study to investigate this effect, where one or two-sided niches are modelled as thin boundaries around the specimen. The vibration damping mechanism of window seals and window frame-wall fixing was not accounted for in numerical model.

The nonlinear sound absorption of the window frame material should be also modelled. Generally, at lower frequency (<500Hz), the sound absorption coefficient of dense wood material is low and at higher frequency (>500 Hz), the sound absorption coefficient is high. However, especially at higher frequencies, the sound absorption coefficient of lower density species may be greater [8]. This nonlinearity of sound absorption coefficient for wood should be incorporated in future studies.

5. Conclusions

The proposed numerical approach, although simplified (it does not contain damping effects of the window fixation, nonlinearities of material sound absorption coefficient and does not consider acoustic coupled effects) gave satisfactory results in the mapping of the experimental sound insulation curves of windows.

The detailed comparison between numerical and experimental results exposed, that numerical results are not exactly the same as in the experimental method. There are still several modelling aspects to account for.

The achieved numerical accuracy should be useful when examining trends in sound insulation as a function windows design parameters, such as different glazing types, frame dimensions, frame material type, etc.

In the future numerical studies can be completed, however not without additional expense of computational cost, which may be disadvantageous in when rapid assessment of the given window configuration is needed.

Acknowledgments

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