Seventh International IBPSA Conference
Rio de Janeiro, Brazil
August 13-15, 2001

SIMULATION OF SOUND INSULATION PROPERTIES OF 'VACUUM ZAPPI FACADE PANELS'

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ABSTRACT

This paper reports on an ongoing research project aiming at prediction of the sound insulation properties of a specific type of facade panel by means of computational tools and experiments. Mentioned facade panels consist of two parallel sheets with a cavity in between. To improve the sound insulation properties the air pressure in the cavity will be lowered. To avoid unacceptable distortion the sheets will be connected by means of so-called 'spacers'.

For these facade elements no formulae are available to predict the sound insulation properties. Therefore the applicability of the computer simulation tool ANSYS has been investigated. First simulation attempts and related results will be discussed..

KEYWORDS

Computer simulation, sound insulation, facade panels, cavities with connecting spacers.

INTRODUCTION

The ongoing 'Zappi' research project at Delft University of Technology, Faculty of Architecture, focuses on development of highly transparent constructional elements such as facade panels, floor slabs and beams. Because of the failure behavior of customary glazing material it is clear that the here mentioned glazing material can not be applied for development of the before mentioned constructional elements. Main research challenge in the field of material science therefor is to develop transparent constructional elements with a failure behavior comparable to steel. Recently some remarkable results have been achieved [1,2].

However it is clear that in designing a transparent building special attention should be paid to important building performance aspects such as indoor climate and energy consumption. In order to fulfill requirements concerning mentioned quality aspects the performance of Zappi elements has to meet certain Standards, for instance in the field of thermal and acoustical insulation and transmittance of sunlight. This paper focuses on prediction of the sound insulation properties of Zappi-facade panels.

From basic acoustical laws it is clear that a substantial improvement of the sound insulation properties can be achieved by reducing the air pressure in the cavity (in comparison with the atmospheric air pressure). It is clear that such a reduction of the air pressure will result in a distortion of both transparent sheets. However because of existing requirements in the field of visual comfort in general the here mentioned distortion will be unacceptable.

'Spacers' are needed to avoid contact between both sheets and can also be used to avoid distortion. Former research of an Australian research group at the University of Sydney [Collins & Simko] proved that the negative effect of applied 'spacers' with small contact areas in the cavity of 'vacuum panels' on the thermal insulation properties was negligible. However the impact of these 'spacers' on the sound insulation properties of these panels so far has not been investigated. In this paper first efforts of our research group to predict sound insulation properties of vacuum Zappi facade elements with spacers in the cavity will be discussed.

Since no formulae exist to predict the sound insulation properties of the here-discussed type of Zappi facade elements, measurements in approved sound insulation rooms and computer simulation therefor seem the only way to predict the sound insulation properties of the here discussed category of facade elements.

During the here discussed research project the following steps will be taken: investigation of the suitability of the computer tool ANSYS to model the sound insulation behavior of the Zappi-panels, measurement of sound insulation values of prototype panels in an approved sound insulation room and finally investigation of the impact of various design parameters on the acoustical performance of the panels. This paper deals with the first mentioned step.

APPROACH

As a first step a cavity facade panel without ‘spacers’ and with atmospheric air pressure in the cavity has been be considered. The following simulation aspects will be discussed:

- Modeling of the panel and the air mass in the room behind this panel (ANSYS).
- Pulse response method (MATLAB).
- Comparison of ANSYS-results with results generated by means of a ‘home-made’ (and validated) multi-layer computation method.

CALCULATION METHOD

1. Definition of ‘sound transmission’

The aim is to calculate the transmission coefficient t of a facade panel, which is the quotient of the transmitted sound intensity I_t at the backside of the construction and the sound intensity I_0 in the sound waves undisturbed by sound waves reflected by the facade panel [3]:

$$t = \frac{I_t}{I_0} = \frac{\mathrm{Re}(p_t^* v_t)}{\mathrm{Re}(p_0^* v_0)} \qquad (1)$$

where p represents the sound pressure as a function of time en v gives the particle velocity as a function of time. The asterisks denote the complex conjugates of the sound pressures. In practice the transmission is often expressed by the sound resistance R in decibels, defined by the following formulae:

$$R = -10 \log t \ \ [\mathrm{dB}]$$

An other useful variable is the impedance, defined as the (complex) quotient between the sound pressure and the particle velocity. So, for instance for the impedance at the indoor side of the panel, we find:

$$Z_t = p_t / v_t$$

Due to the reflection of sound waves by for instance the walls, room dimensions as well as applied materials have an impact on p_t and v_t. This means that the sound transmission also in some way depends on certain room characteristics. Only in case of 100% absorption by all surrounding surfaces, this impact will be nil. In a following section the effect of wall reflections on p_t will be discussed.

2. ANSYS-modeling

An “air chamber” is situated at the backside of the cavity panel to provide for a proper impedance.

For the modeling of the indoor air and surrounding walls (figure 1) a number of different ANSYS elements is required. The ‘solids’ are represented by element type 82, which is an element consisting of eight nodes. See also paragraph ‘Plate damping’. All air elements (type 29) consist of four nodes. This type of element is subdivided into one type for a “normal” element and one for an air element coupled to a non-air element. The elements along the edges are given by type 129, representing a (total) absorbing edge. The dimension of each air element equals 4 cm by 2 cm, which is less than 1/6 of the applied wavelength.

An air pressure (p_{in}) has been defined and applied on one or more nodes used to model the panel. The other three variables (v_{in}, p_t, v_t) have been computed by ANSYS.

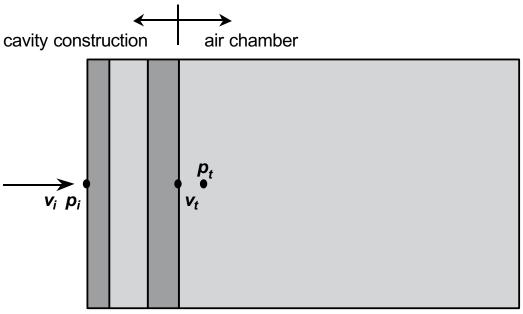


Figure 1: The configuration used in ANSYS.

3. The pulse method

In common acoustics harmonic solutions are often used, calculating a series of frequencies. In ANSYS too this method can be applied. However, we prefer a pulse method (denoted as “time history” in ANSYS), since the impact of sound waves reflected by the surrounding walls of the air chamber on the sound pressure can be traced easier.

Because we want to calculate the sound transmission for a total range of frequencies, a Fourier transform is used to transform the time domain into the frequency domain. The so-called ‘Ricker-pulse’ appears to be very suitable for this purpose. See figure 2a.

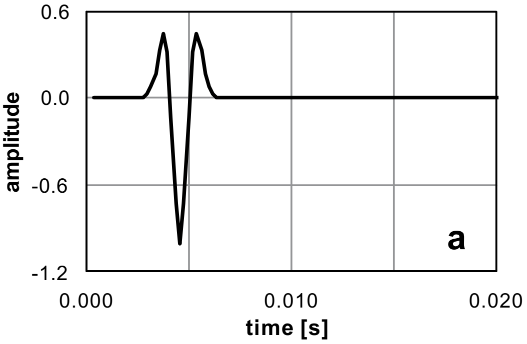


Figure 2a: The ‘Ricker pulse’ used as input (p_{in})

The time plot-equivalent in the frequency domain is shown in figure 2b.

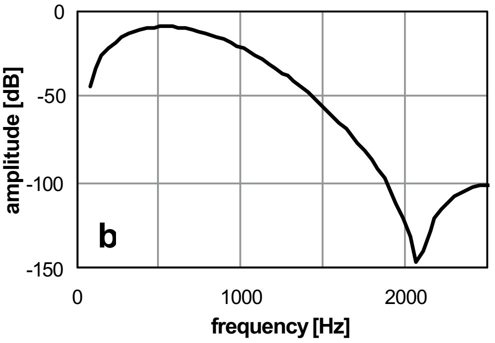
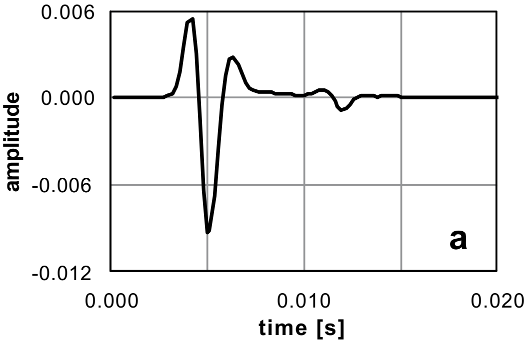


Figure 2b: The Ricker pulse in the frequency-domain

The reason to use the Ricker pulse can be seen in the frequency domain: the influence of side lobes (in figure 2b only one side lob is shown) is very low as they are almost 100 dB down.

Figure 2a gives the sound pressure applied to the front side of the panel. After performing an ANSYS-simulation at the backside of the panel a similar pulse is found. See figure 3.



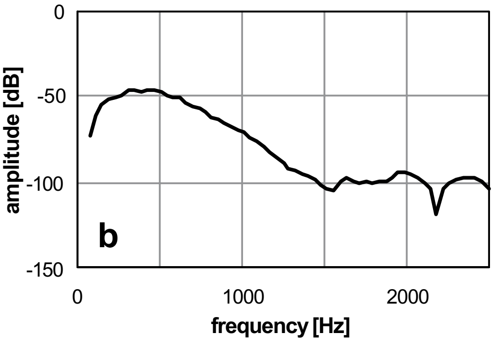


Figure 3: The resulting pulse (p_t) at the backside of the facade panel. Figure 3a gives the time domain; figure 3b shows the frequency domain.

The time plots at the front and the back of the panel differ in amplitude (because the transmission through a construction is small) and in shape (because the transmission is a function of frequency).

The ripple at –100 dB (in figure 3b) at the back of the construction is caused by the limited accuracy, chosen in the ANSYS program. The four values p_{in}, v_{in}, p_t, v_t are all calculated in ANSYS in the time domain. They are exported to computer memory as the actual Fourier transforms are performed in MATLAB.

3. Computation of I_t and I_0.

The reduction of the sound intensity is given by equation 1. From the four required variables only p_t and v_t are known after an ANSYS-simulation run. An extra step is necessary to transform p_{in} and v_{in} values into p_0 and v_0 values. The scheme of figure 4 is used to illustrate this translation.

The upper drawing gives the scheme representing the performed ANSYS calculations. Z_{ac} represents the impedance of the air chamber. If the chamber does what it is supposed to do, this impedance equals that of air. Small deviations are caused by reflections of the air chamber walls.

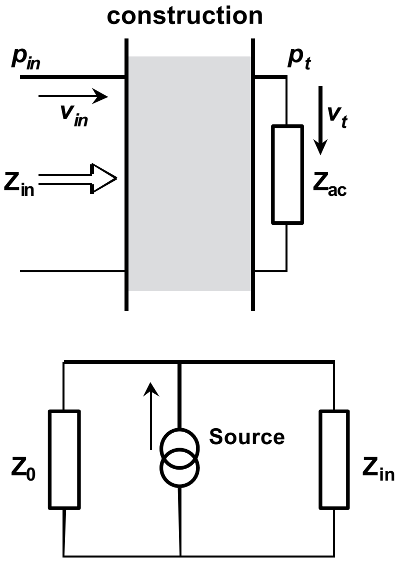


Figure 4: Electrical analogons of the applied calculation method to determine the values of v_{in}, p_t and v_t (upper figure) and to convert Z_{in} into Z_0 (lower figure).

Since p_{in} and v_{in} are calculated by ANSYS, the value of the impedance Zin at the front of the facade panel is known. In the second step (performed in MATLAB) we assume a sound source in air at the front of the construction. One extra impedance counts for the sound waves travelling from the construction into free air.

From the lower scheme in figure 4 both intensity values from equation 1 can be found as:

$$I_t = \mathrm{Re}\left(p_t^* v_t\right) = \left|v_t\right|^2 \mathrm{Re}\left(z_t\right)$$

$$I_0 = \mathrm{Re}\left[\left(p_{in}\frac{Z_{in}+Z_0}{2Z_{in}}\right)^*\left(v_{in}\frac{Z_{in}+Z_0}{2Z_0}\right)\right]$$

$$= \left|\frac{p_{in}+Z_0 v_{in}}{2Z_0}\right|^2 \mathrm{Re}\left(Z_0\right) \qquad (2)$$

4. Plate damping

At the start of the project harmonic solutions have been used. The main reason to exchange the harmonic approach for the pulse method was the wish or need to detect the impact of single plate vibrations on occurring sound pressures. Plates with fixed edges (see also figure 8) do vibrate (like a guitar string), mainly at frequencies in the order of 10 to 50 Hz (depending on the plate thickness). If for instance the facade panel is used to prevent nuisance in a building due to traffic noise, these vibrations are of no interest to the building engineer and therefor can be neglected. However from the modeling point of view it is obvious the occurrence of these vibrations can not be ignored.

In ANSYS mentioned vibrations can be damped by introducing 'material losses'. Material losses are defined as the quotient of the imaginary and real parts of Young's modulus. Figure 5 shows the ANSYS-simulated dynamic response due to a Ricker pulse in case of a facade panel with or without damping.

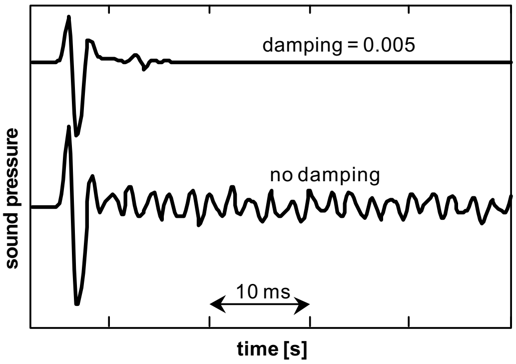


Figure 5: The influence of plate damping for a 4-mm glass plate. Vertical axis is arbitrary.

5. Air chamber dimensions

In ANSYS special elements can be defined to reduce sound wave reflections by the surfaces surrounding the air chamber, shown in figure 1. To reduce these reflections as much as possible, the boundaries of the chamber have to be perpendicular to the sound propagation direction and hence it is suggested in ANSYS manuals to model the chamber by using circular elements with the facade panel positioned in the center. Some of the experiments based on the here mentioned approach, by us but also by other researchers, were not too successful. Therefore we decided to use a rectangular room, as already given in figure 1.

Using a rectangular room model and an 8-mm glass sheet it has been possible to reproduce the impact of mentioned reflections on occurring sound pressures. Simulation results are shown in figure 6.

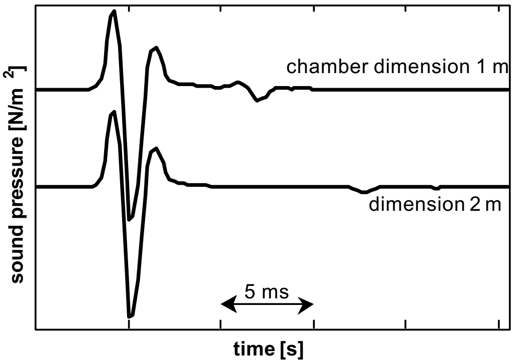


Figure 6: The influence of reflections from the rear side of the air chamber. Sound pressure values are arbitrary.

The elapsed time between Ricker pulse and pressure disturbance due to reflections will depend on the room dimensions. For a chamber depth of 1 m and 2 m the elapsed time will be respectively 6 and 12 ms. As can be seen from figure 6 these elapse time values are also found by the here discussed ANSYS-simulation. Even more important is that the amplitude due to sound wave reflections decreases quite rapidly with increasing chamber length.

The conclusion can be drawn that by enlarging the air chamber depth, the 'disturbance' due to wall reflections can be eliminated. However, since the air chamber model consists of a number of finite elements with maximum dimensions of 1/6 of the applied wave length, enlargement of the air chamber will result in an increase of the number of elements and therefor of the required computing time.

Figure 7 shows the influence of the reflection when a 'Fast Fourier Transform is performed. Without reflections the frequency plot is very smooth. Some small oscillations occur around the mean value when the reflection is present in the pressure plot. Here again the oscillations almost completely disappear when the chamber length is 2 m.

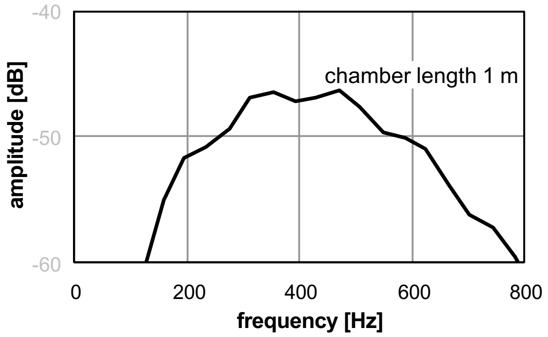


Figure 7: Oscillations in the frequency plot due to reflections from the rear side of the air chamber. Vertical values are arbitrary.

The results discussed in the next paragraph have been calculated for an air chamber depth of 2 m. The width of the air chamber always equals 1 m. So far the influence of the chamber width appeared to be very small when applying the sound absorbing element type provided by ANSYS.

SOME PRELIMINARY FINDINGS FOR THE CAVITY CONSTRUCTION

ANSYS-calculations have been done for a glass-air-glass cavity panel with dimensions of respectively 4-10-6 mm. Calculations are performed in a two-dimensional model with special nodes at the edges of the inner glass sheet to fix the position of the panel. See figure 8.

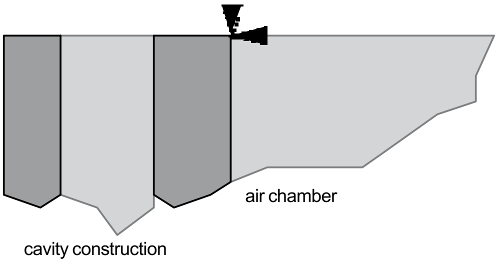


Figure 8: Detail from figure 1 to illustrate constraints as used in the model. The edges of the inner glass sheet are fixed in x- and y-direction.

Computations have been done for two different air pressure values in the cavity: atmospheric pressure and one-tenth of the atmospheric pressure. Generated transmission coefficient values are shown in figure 9.

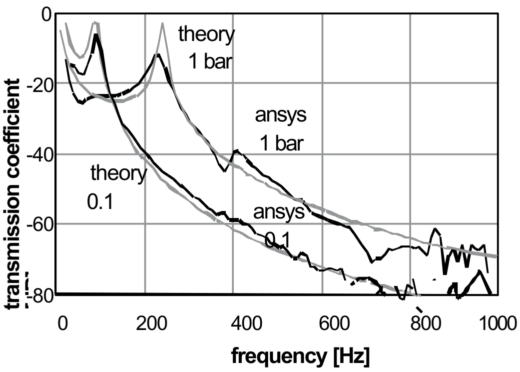


Figure 9: Transmission coefficient for a cavity construction of two glass plates of 4 and 6 mm with a 10 mm cavity. Results are compared with calculations from a multi-layer calculation method.

The computational results generated by ANSYS have been compared with computational results obtained by using a so-called ‘multi-layer calculation method’. This model has been developed by our research group for prediction of sound insulation values of multi-layer constructions. The sound incidence may be normal, oblique or from diffuse fields. However this computer model has one major drawback. It is based on the assumption of infinite dimensions in both lateral directions. Therefore it is impossible to apply this model in case of cavity panels with spacers in the cavity. For that reason realization of an approved ANSYS model is our goal. However for multi-layer construction elements with infinite dimensions in the lateral directions (as calculated in the example of figure 9) both models can be used. Comparison of computational results therefor is allowed.

From the results shown in figure 9 it can be concluded that they correspond very well. The ANSYS calculations show a deviation at about 400 Hz for the atmospheric case. This is due to the plate dimensions of l m.

FUTURE RESEARCH

Besides refinement of the here discussed ANSYS-model our next step will focus on expansion of the model. Modeling of the sound insulation properties of the here discussed multi-layer construction elements only can be seen as a first modeling step. As stated before adequate and reliable modeling of the sound insulation performance of cavity panels with various types of spacers is our final goal.

The impact of applied gas fillings in the cavity as well as the impact of the pressure of the gas fillings on the sound insulation behavior will be further explored.

Comparison of computed results with measurement results obtained by using approved sound insulation rooms also is an important issue. Various proto-type facade panels with spacers in the cavity have been built. See figure 10.

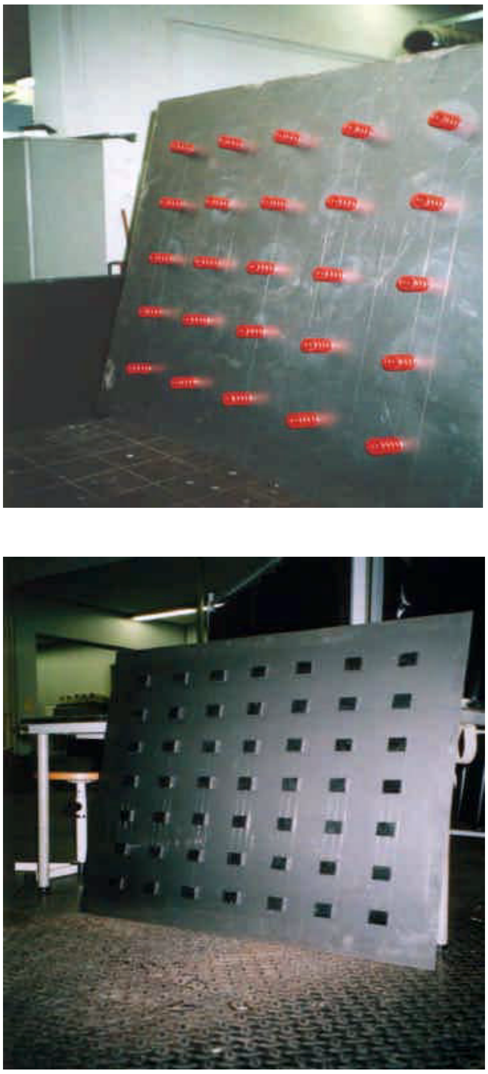


Figure 10: Proto-type of cavity panel with spacers.

The impact of a number of panel-design decisions will be investigated such as: material applied for the spacers, number of spacers per square meter, pressure and type of the gas filling in the cavity. In figure 11 some first measurement results are shown for a cavity without spacers and a cavity with rubber spacers.

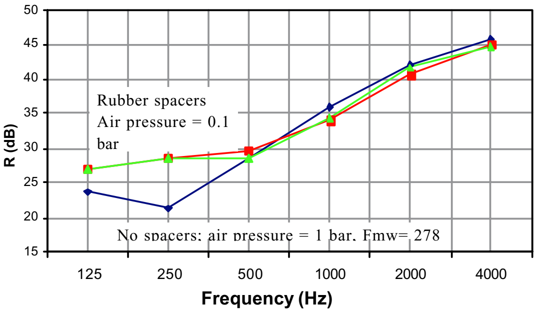


Figure 11: Measurement results for two specific prototype cavity panels.

CONCLUSIONS AND REMARKS

With regard to the applicability of the ANSYS computer program to simulate the sound insulation characteristics of facade panels, the following (partly preliminary) conclusions can be drawn:

Ç For a multi-layer cavity panel without spacers and a for a specific type of panel load, the Ricker pulse, unknown air pressures and related particle velocities, required to compute wanted sound transmittance values, can be simulated in a reliable way using the ANSYS-computer program.

Ç Also the impact of occurring reflections of sound waves by the walls of an air chamber can also be reproduced accurately.

Ç In modeling the panel construction it is possible and necessary as well to take plate damping into account.However to compute pressure and particle velocity values in the undisturbed incoming sound wave (required for computing the sound resistance R) an additional computational model has to be available.

Ç Computed sound insulation values, based on ANSYS-simulation results, for a multi-layer cavity panel without spacers correspond well with computational results, obtained by a ‘home made’ and validated computer program for multi-layer facade elements.

Ç The impact of a reduction of the gas filling pressure in the cavity on the sound insulation values also can be reproduced. Again generated results correspond with the results, obtained by using the before mentioned multi-layer computer program.

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NOMENCLATURE

I_0	Sound intensity when panel is absent	[W/m^2].
I_t	Sound intensity at the back side of the construction	[W/m^2].
p_0	Sound pressure when panel is absent	[Pa].
p_{in}	Sound pressure at the front side of the construction	[Pa].
p_t	Sound pressure at the back side of the construction	[Pa].
R	Sound resistance	[dB].
t	Transmissioncoefficient	[-].
v_0	Acoustical particle velocity when panel is absent	[m/s].
v_{in}	Acoustical particle velocity at the front side of the construction	[m/s].
v_t	Acoustical particle velocity at the back side of the construction	[m/s].
Z_0	Acoustic impedandce when panel is absent	[kg/m^2/s].
Z_{ac}	Acoustic impedandce for the acoustic chamber at the back side of the construction	[kg/m^2/s].
Z_{in}	Acoustic impedandce at the front side of the construction	[kg/m^2/s].
Z_t	Acoustic impedandce at the back side of the construction	[kg/m^2/s].