Influence of sealing on the acoustic performance of PVC windows

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ABSTRACT: The review of results of laboratory tests carried out for PVC windows shows the considerable differences in the sound reduction index obtained for windows with the same typically used glazing. The sealing is examined as one of the technical factors that can be the cause for such a difference. Two main aspects are considered; the joint between casement and frame as the direct path of sound transmission and the weatherstrips as the supporting element of window sash. In the first case the perfectly tight and untightened windows are considered separately. Reduction of air tightness always causes decrease in sound insulation but the effect is not the same in each investigated case. The weatherstrips are also the assembly elements that affect boundary conditions for the whole casement. Some evidence indicates that the gaskets acting as a casement supporting element influence the sound insulation of a window.

1. INTRODUCTION

Window as a part of an external wall has a number of important functions. One of them is protection against noise. Various factors influence the sound insulation of windows and it is not only a question of glazing structure and its components.

A significant number of sound insulation measurements have recently been carried out at the Building Research Institute for windows made of PVC sections. The windows tested belong to different construction systems and were taken from different manufacturers. Although all of them have the same glazing (4/16/4) considerable differences in their sound insulation can be observed. Weighted sound reduction index values are within the range of (32 - 39) dB. However, the R_w index for glazing tested on standard (1230 x 1480) mm samples is not higher than 32 dB. It indicates that the acoustic performance of window is not a simple result of sound insulation of frame and glazing tested on samples of one standard size.

Following such a conclusion more detailed analysis of existing laboratory measurement results obtained for plastic windows was done. Different technical factors were considered, among others the sealing. Junction between fixed and movable members of a window influences its water tightness, air infiltration and also the acoustic performance. In accordance with Polish regulations in the case of buildings with natural ventilation (which are prevailing) windows should not be perfectly tight. Tight windows can be used only in buildings with mechanical ventilation or another system of air inlet.

Results of laboratory measurements show that the reduction of window air tightness causes a significant decrease in their sound insulation, particularly in the case of windows with high insulating glazing. The drop of sound reduction index values is, however, different even when taking into account only windows with the same glazing.

When analysing the influence of sealing on the acoustic performance of a window, two main aspects are considered; the joint as the direct path of sound transmission and weatherstrips as the supporting element of the window casement. In the first case the windows perfectly sealed and windows with reduced air tightness were investigated separately. In total over 300 results of laboratory tests taken within the period of 1994 - 2000 were analysed. For chosen samples additional experiments were carried out.

2. NOMENCLATURE

a	Air permeability coefficient, single number index calculated from a(p)
a(p)	Air permeability of the opening joints (normalized to 10 Pa)
C, C_{tr}	Spectrum adaptation terms (EN ISO 717-1)
p	Pressure
R	Sound reduction index
R_w	Weighted sound reduction index (EN ISO 717-1)

R_{A1}	$R_w + C$
R_{A2}	$R_w + C_{tr}$
R-36	Reference curve (EN ISO 717-1) corresponding to R_w = 36dB
Δa	$a(p) - a$

3. PREVIOUS EXPERIENCES

It is known that gaps, slots and unsealed joints between building elements cause reduction in sound insulation. Lewis *(Lewis 1979)* has examined unsealed windows with different frame cross-sections to find how the sound insulation varies with the width of the gaps and whether it differs from one construction to another. The gaps of different shape were investigated. The sound insulation of the unsealed windows was found to be more dependent on the cross-sectional shape of the frames than widths of the gaps.

Szudrowicz *(Szudrowicz 1992)* has found an empirical relationship between air permeability and sound insulation for unsealed wood windows. For different frequency range, the decrease of sound reduction index compared to perfectly sealed windows was determined. The decrease depends on air permeability coefficient, however values of the coefficient were within a very wide range because of the lack of weatherstrips.

The influence of the joint between sash and frame on the acoustic performance of a window is not only the question of a direct path of sound transmission. An experimental investigation on the influence of frame/sash construction on sound insulation for windows was carried out by *(Hoffmeyer 1990)*. For double glazing 8/12/4 the sound reduction index measured in a firm frame was compared with results obtained in 3 different openable windows. In the case of windows the value of weighted sound reduction index R_w was higher by 2-4 dB than for glazing in a frame. The main differences in sound insulation curves can be observed in the middle frequency range. The effect was attributed to the window geometry and modal behaviour. The match between modes in the cavity of the glazing and in the test opening was indicated as a probable reason for the increased sound transmission in the frequency range 250 – 2000 Hz for the glazing in the fixed frame. Such an effect has previously been observed by Gösele & Lakatos *(Gösele & Lakatos 1980)*. The aperture with niches, where the sound pressure level increase along the perimeter, was given as an explanation of the phenomenon. Also Michelsen *(Michelsen 1983)* has found, based on laboratory results, that there is a difference in the sound reduction index using a frame with a sash compared with that using a frame alone. Glazing mounted in a frame with a sash obtained higher values of sound reduction index by up to 5 dB above the resonance frequency. It was explained as a result of decoupling of the grazing modes in the niche from the lateral modes in the air space of the double glazing.

Hoffmeyer *(Hoffmeyer 1990)* has observed an unfavourable effect in the frequency range 630-1200 Hz when testing aluminium windows with two effective weatherstrips in the joint between frame and sash. One tightening was placed on the inner side, the other in the middle of the frame/sash profiles forming an open part of the joint between frame and sash. The resonator effect *(Burges M. A. 1985)* was indicated as an explanation of the decrease of sound insulation around 1000 Hz.

4. ACOUSTIC MODEL OF A WINDOW

From the acoustic point of view a window is a non-homogenous partition composed of elements with different levels of performance. Regardless of the construction and the window type three main elements can be distinguished; frame, glazing and the joint with weatherstrips. The percentage of the area of the respective components in the entire window varies depending on the dimensions and division into sashes.

Taking a simplified assumption that the composing parts of a window as a combined element do not interact, sound insulation of a window can be evaluated from formulas:

$$R = -10lg\tau_e \quad (1)$$

$$\tau_e = \sum_{i=1}^{n} \frac{S_i}{S} 10^{-R_i/10} \quad (2)$$

where R_i = sound reduction index of part i of a window; S_i = area of part i; and S = total area of a window.

Since the area of gaps is hard to determine, it is easier to define their sound insulation with respect to a unit of length. From this assumption, formula (2) takes the following form:

$$\tau_e = \sum_{i=1}^{n} \frac{S_i}{S} 10^{-R_i/10} + \frac{l_0}{S} \sum_{k=1}^{m} l_{s,k} 10^{-R_{s,k}/10} \quad (3)$$

where; $l_{s,k}$ = length of sealed gap; and l_0 = 1 m .

Such a model for determination of sound transmission by building elements from composing parts is accepted in standard *(EN 12354-3)* with note, that it can be used to estimate the influence of a different quality of the sealing than applied for the laboratory measurement of sound reduction index of an element. Another remark saying that "this is not to be

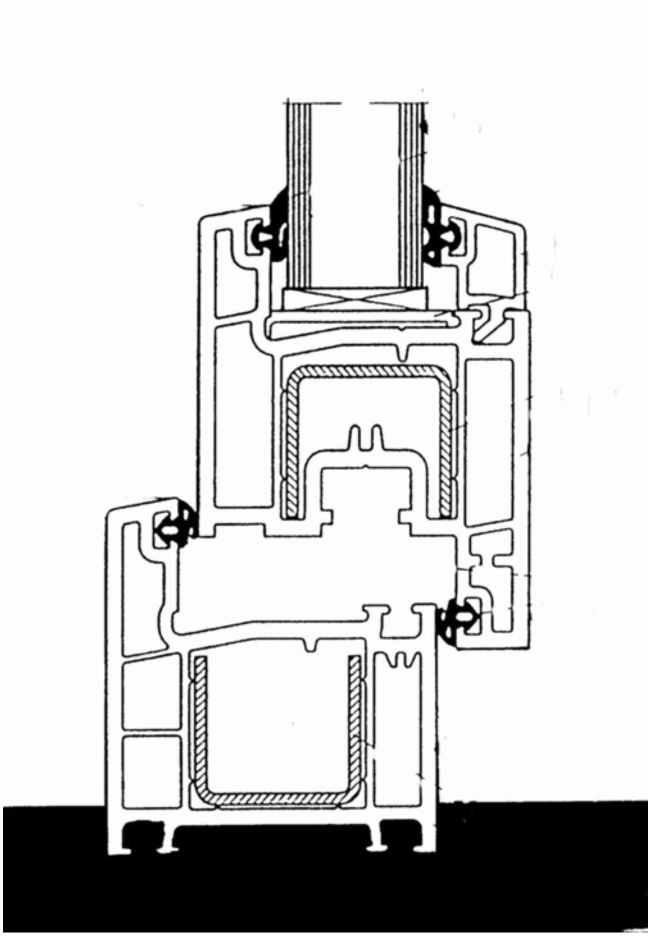

Figure 1. Cross section of window frame, joint between fixed and openable parts.

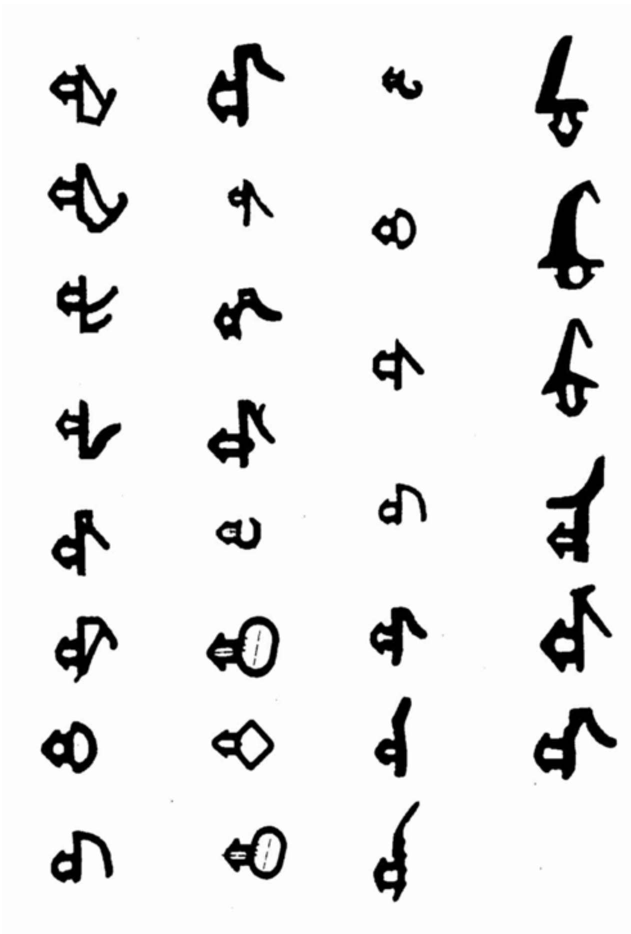

Figure 2. The shapes of weatherstrips used in investigated windows.

used to state the acoustic performance of elements composed of several parts" can be found. There are few reasons for such restrictions. One of them is that the standard method to determine the sound reduction index R_s per unit length of sealed gaps and joints between elements is not yet available. Standard *(EN 12354-3)*suggests that the most practical way for determining this quantity is to carry out measurements on particular elements with and without additional sealing of gaps or joints. But in the case of PVC and aluminium windows the joint between fixed and movable parts is quite different than in traditional wood windows. There is no staggered gap or crack but rather an additional chamber closed within the frame cross section by the set of internal and external weatherstrips *(see figure 1)*.

5. DESCRIPTION OF SEALING

Weatherstrips are usually made of EPDM in a shape of a lip or tube with open or close section. The shapes of gaskets used in analysed windows are shown in figure 2. A set of two weatherstrips put in different positions is most frequently used; the external and internal gasket (EI), or the central and internal gasket (CI). Sometimes tightenings are applied in all three positions i.e. the inner, central and external gaskets are used simultaneously. There are also systems of profiles which construction gives the possibility of using sealing in any given position. The weatherstrips are fastened in the channels on the perimeter of casement and frame.

To meet the requirements concerning air infiltration in buildings with natural ventilation tightness of windows should be reduced to ensure proper ventilation even if the window is closed. Such a reduction is obtained by various methods like;

- labyrinth-like cuttings of parts of weatherstrips replaced by pieces of perforated or flat gasket,
- special "ventilation" weatherstrips with rough surface which provide a micro gap on the whole perimeter,
- micro-opening of window casement,
- air inlet devices installed in window sash/frame.

The length and position of cuttings is determined individually in an empirical way. The untightened window should meet the requirements concerning the infiltration, water tightness and all the other technical characteristics.

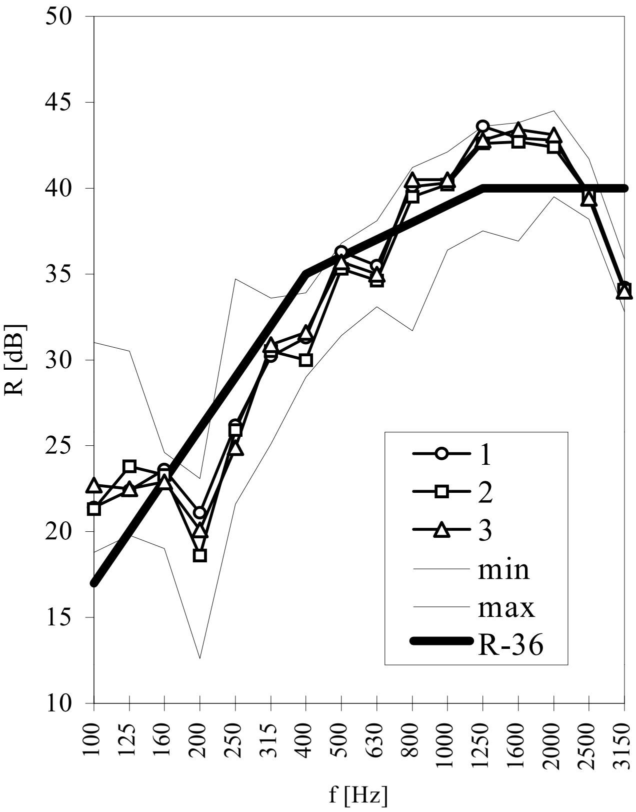

Figure 3. Sound insulation of windows with the same size and glazing, taken from one manufacturer.

6. RESULTS OF STANDARD TESTS

6.1 Samples

The analysis is based on results of laboratory tests carried out on 156 windows made of PVC sections belonging to 27 different systems. For each system 4 – 8 samples taken from a single producer were tested. All windows have the same 4/16/4 glazing which consists of two 4 mm panes separated by 16 mm space of dry air.

Two sets of results were investigated separately; obtained from windows with perfect and reduced air tightness. In both cases the same samples were tested once before and then after air tightness reduction. In total 312 results were analysed.

In the examined group of windows with the same glazing there were windows of three types, with identical dimensions within each of the types:

-double side hung casement (DC)	1465 x 1435 mm
-combined double casement (CO)	1465 x 2195 mm
-balcony door (BD)	865 x 2195 mm

6.2 Measurement conditions

Measurements were carried out on one and the same test facility consisting of two reverberant rooms with irregular shape. The volume of each room is about 100 m^3. The test facility with suppressed flanking transmission complies with ISO 140 standard. Measurements were taken with the same equipment operated by the same operator. Windows were installed in the filling wall consisting of two layers of calcium silicate brick erected on both side of the acoustic break of the facility. Space between these two layers was filled with sound absorbing material.

Windows were installed by the same team of workers. Good reproducibility of montage conditions was confirmed by the results of measurements carried out on windows coming from the same system, taken from one manufacturer, with identical shape and the same dimensions. All of them were glazed with the same 4/16/4 units. An example of results is shown in figure 3. Sound insulation curves obtained from three windows which were put in turn into the test opening are of nearly identical shape. Several such comparisons were analysed. In each case the similarity of sound insulation curves was very good. Figure 3 shows also the envelope curves for investigated semi identical windows but taken from different manufacturers. The area defined by these curves is rather wide. It indicates that there can be some individual factors connected with production conditions that influence acoustic performance of windows made of identical elements.

The same windows were subjected to other tests, such as wind resistance, water tightness, mechanical resistance and air permeability tests. Hence, there were complete technical characteristics of analysed windows. Particularly important data was the air permeability coefficient values measured for each of the samples.

6.3 Results

A number of earlier measurements had been carried out within the range of (100 - 3150) Hz. Recent measurements were done at (100 – 5000) Hz 1/3 octave bands. Single number quantities were calculated in accordance with PN EN ISO 717-1. From January 2000 for the evaluation of acoustic performance of building elements new sound reduction indicators R_{A1} and R_{A2} have been used. In the case of external partitions, including windows, the R_{A2} index is the basic assessment criteria. The values of all three single number indices as well as sound insulation curves were analyzed.

For samples coming from each window system the results were collected together in one figure. The envelope curves obtained for all results are shown in the background. They indicate the area in which all sound reduction index values achieved within the analysed group of windows with the same glazing can be found. As an example results obtained for perfectly airtight windows belonging to system no. 5 are shown in figure 4. R_w values are within the range of 35 – 38 dB, reference curve R-36 corresponds to the average value calculated for six results presented

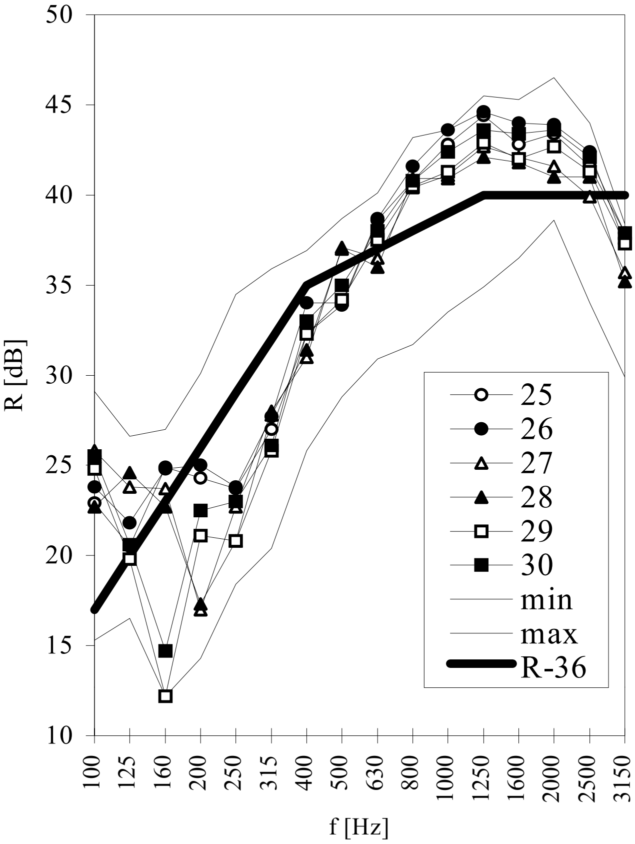

Figure 4. Windows from system No 5, perfectly tight.

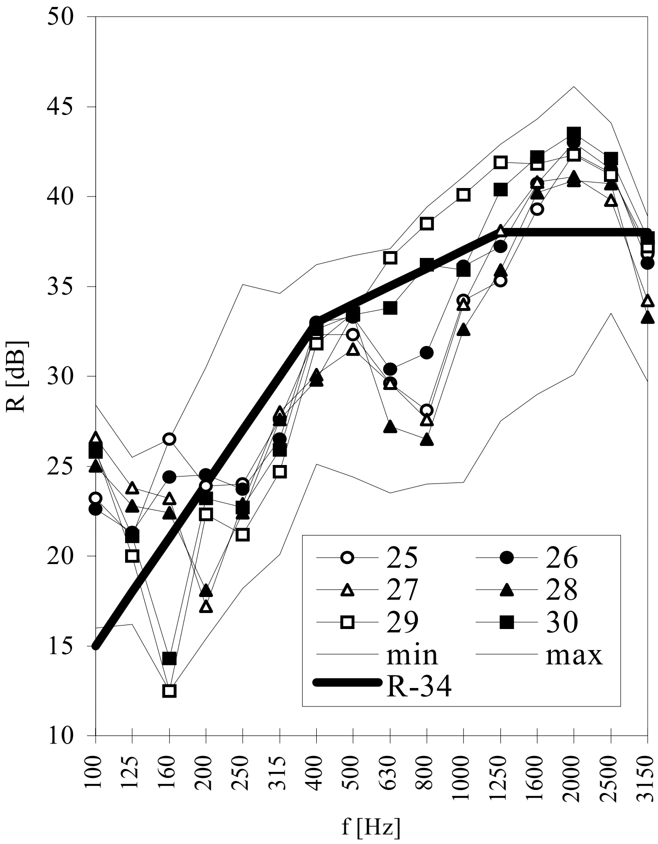

Figure 5. Windows from system No 5, reduced air-tightness.

in the figure. Figure 5 shows results for the same windows after untightening (R_w = 32 – 35 dB). The samples are denoted by numbers (25 –30). Within system no.5 two windows of each type (DC, CO and BD) were examined. The results are composed in couples depending on the window type. The reference curve indicates which frequency decides on the achieved value of R_w index. Similar sets of results were prepared for the remaining 26 window systems.

7. DIRECT PATH OF SOUND TRANSMISSION

7.1 Windows perfectly tight

The type, shape and position of weatherstrips were examined. No significant influence of the type or shape of the gasket's sections on the sound insulation was observed. However the location of external weatherstrip makes some difference *(Hoffmayer 1990)*. In the case of windows with central gasket (CI) a considerable drop in sound insulation occurs around 1000 Hz in comparison with (EI) systems. Such a tendency can be observed in each considered case. Decrease in sound insulation is evident when results obtained for identical windows sealed in a different way are compared. For windows with 4/16/4 glazing this local decrease usually has no influence on single number quantities. For windows with high insulating glazing the (EI) system of sealing is more advantageous than (CI).

For investigated windows, actual values of air permeability coefficient "a" are within the range of (0,0 – 0,2) m^3/mhdaPa$^{2/3}$ ("a" is the single number index used in Poland, is calculated from the air permeability measured for different pressure steps between 60 and 300 Pa tested in accordance with EN 1026 but normalized not to 100 but to10 Pa). When analyzing the results of acoustic measurements in comparison with the values of this coefficient changing within such a narrow extend no strict relationship can be observed. From the noise reduction point of view, such windows can be recognised as perfectly tight.

To prove this conclusion, additional tests were carried out for windows with different glazing. Measurements for the same window before and after additional sealing of joints with use of putty were done *(see EN 12354-3)*. No tendency indicating the increase of sound insulation after additional sealing was observed. Usually the influence of a junction as a direct path of sound transmission on the sound insulation of window occurs when the air permeability coefficient exceeds 0.2 m^3/m·h·dPa$^{2/3}$ particularly for windows with glazing having a better sound proof performance.

A certain dependency between the air permeability coefficient and the decrease in the sound reduction index caused by the lack of perfect sealing ex-

Figure 6. Decrease of sound insulation as an effect of window air tightness reduction, mean values.

ists in the case of traditional wood windows *(Szurdowicz 1992)*. However, the junction between fixed and movable elements for such windows is quite different than in PVC or aluminium windows where the joint has a form of an additional chamber in the whole cross section of frame. This chamber is closed by external and internal weatherstrips. The mechanism of sound transmission via the joint is different than in the case of open staggered crack.

This additional chamber has lower sound insulation than the other parts of the frame because of the lack of metal profiles which are present within the sash and frame sections as a reinforcement *(see figure 1)*. A significant influence of the lack of these profiles on the sound insulation of frame and the whole window has been found as a result of examining of the PVC frames.

7.2 Windows with reduced air tightness.

Reduction of a window's air tightness usually causes a significant decrease in sound insulation. The effect is different within a considered frequency range. Also a different method of untightening used for windows of various systems gives different results. The decrease of sound insulation depends rather on the manner of air tightness reduction than on the final value of air permeability coefficient. Different methods of a window's untightening were considered;

– cutting of small parts of weather-strips in a way that the slots form a labyrinth,
– using perforated or flat weather-strips for part of the joint,
– using "ventilation" weather-strips with a rough surface giving a small gap on the whole casement-frame joint,
– assembling special inlet devices into the sash/frame,

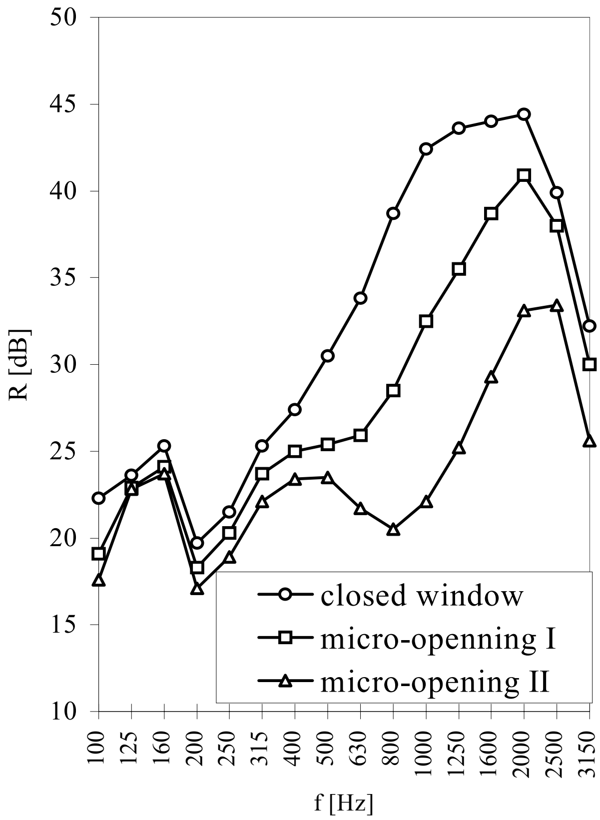

Figure 7. Sound insulation of single side hung casement window in different level of micro-opening.

– using micro opening of casement.

Local small slots made in the weatherstrips (labyrinth cuttings, flat or perforated seals) give better results means a smaller decrease in sound insulation, than continuous gaps on the whole perimeter. The position of cuttings is also of crucial importance. They should form a proper labyrinth inside the window frame which acts as a sound attenuator. Suitable location of cuttings depends on the window type and its division into sashes. In systems with central gasket (CI) reduction of sound insulation is always bigger than in (EI) systems. Good results can be obtained with simultaneous application of external, internal and central weatherstrips. It gives better possibilities of forming a proper labyrinth.

Local cuttings usually cause a decrease in the sound insulation in the (500-1600) Hz frequency range. Figure 6 shows averaged values of sound reduction index decrease in the case of PVC windows with 4/16/4 glazing. The dipper drop can be observed at (800 – 1000) Hz 1/3 octave bands.

The other methods of air tightness reduction which cause continuous a gap on the whole perimeter ("ventilation" gaskets or micro-openings) result in a bigger decrease in sound insulation. Because of absence of a labyrinth the effect of a gap occurs in the wider range of frequency. As an example, the results obtained for a single side hung casement window which was closed, then open at different levels

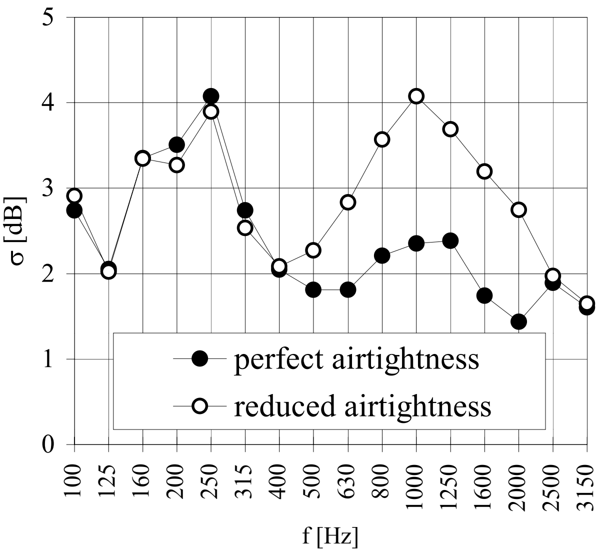

Figure 8. Standard deviation of the sound insulation test results for 156 windows with the same 4/16/4 glazing.

of micro-opening is shown in figure 7. The effect of a continuous micro gap can be observed also in the lower frequency area so it has greater influence on the value of single number quantities. Using "ventilation" gaskets gives similar results.

In the case of analyzed windows with reduced air tightness actual values of the air permeability coefficient were within the range of (0.5 - 0.8) $m^3/mhdaPa^{2/3}$. However, the decrease in the sound reduction index was more dependent on the untightening method than on the initial and final value of the coefficient. No strict relationship between the final value of the coefficient and the decrease in the sound insulation could be found. Figure 8 shows the standard deviation of the analyzed test results. In the case of untightened windows it increases at low frequencies (as was for perfectly tight windows) and also within the range of (500 – 2000) Hz, where the contribution of different methods of air tightness reduction occurs.

A single number quantities also diminish as an effect of untightening. For windows with 4/16/4 glazing (156 windows were investigated) a decrease in weighted sound reduction index values was within the range of $\Delta R_w = (0 - 7)$ dB. Less affected was the R_{A2} index which is more dependent on the sound reduction index obtained at low frequency.

8. ASSEMBLY CONDITIONS

8.1 Glazing

It is known that the method of mounting the glazing in a frame can influence its acoustic performance *(Cops A. Myncke H. 1977)*. Rigid assembly of a pane's edges results in lower sound reduction index in comparison with use of soft putty. The effect occurs at the coincidence frequency and adjacent bands. It can be illustrated by the results of sound insulation measurements carried out on 4/16/4 glazing with standard dimensions 1230x1480 mm. The panes were initially installed with the use of soft putty in accordance with the recommendations of the ISO 140-3 standard. Then the tightness of fixing was increased with wooden wedges placed evenly on the perimeter. Comparison of results is shown in figure 9. The weighted sound reduction index decreased by 2 dB. A similar tendency was observed for several other samples of single panes of different thickness.

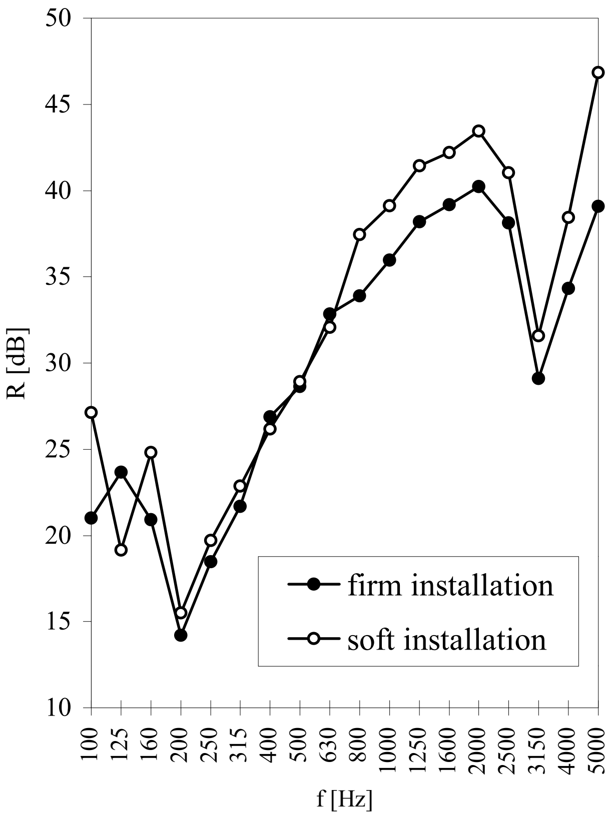

Figure 9. Influence of the method of a glazing installation in the frame on its sound insulation.

Such an effect also occurs for other building structures. In the case of lightweight plasterboard walls the decrease of sound insulation in medium and high frequency can be observed as a result of toughening of gypsum mortal on the edges of plasterboard panels. Some more similarities between behaviour of lightweight frame walls and glazing can be found *(Nurzynski 2002)*.

8.2 Casement

Weatherstrips are the supporting elements that influence boundary conditions for the whole casement. Sound insulation of a single side hung casement window and fixed window of the same size, with the same glazing, taken from the same manufacturer are compared in figure 10. An openeble window has

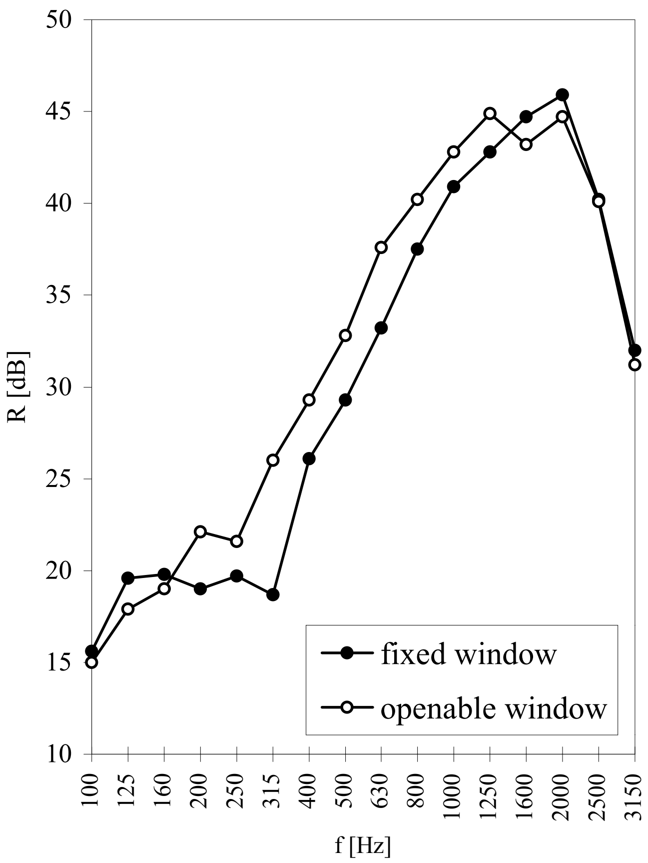

Figure 10. Measurement results; fixed and openable windows are taken from one manufacturer have the same dimensions and glazing.

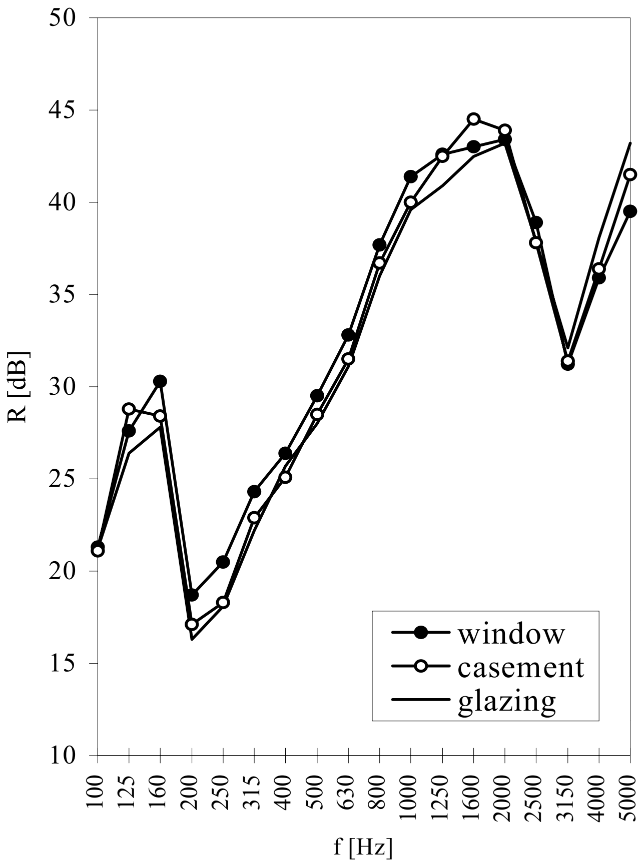

Figure 11. Measurement results; sound insulation of a single casement window, then the casement alone and the glazing removed from casement.

better sound insulation by (2 - 4) dB in the middle frequency range. Another several couple of results confirm such a tendency.

There is one main difference between these two windows. In the case of a fixed window, glazing is inserted directly into the frame mounted firmly in a massive wall. In the openable window, glazing is inserted in the same manner, not directly into the frame, but in the casement (see figure 1). The whole casement is put into the frame but weatherstrips separate these two elements. It can be concluded that the resilient weatherstrips influence the sash boundary conditions and cause the increase of sound insulation of the whole window.

Direct measurements carried out for PVC windows with 4/16/4 glazing confirm such a hypothesis. The initial test was taken on a single side hung casement window, then for a casement alone taken from this window and mounted rigidly in the test opening. In the end the glazing removed from casement and mounted in accordance with ISO 140 was investigated. Results normalized to the area of glazing are shown in figure 11. The single number indices obtained for the window are 2-3 dB higher than for the casement itself. The sound insulation curves for casement and glazing are nearly the same. It illustrate the range of possible influence of sash assembly conditions on the sound insulation of window.

It can be one of the reasons that the weighted sound reduction index of investigated PVC perfectly tight windows with 4/16/4 glazing was in the range of (32 – 39) dB while the glazing itself tested on standard (1230 x 1480) mm samples obtain no more than $R_w = 32$ dB.

Other observations follow from more detailed analysis of air permeability test results. It was observed, that the nature of changes of a(p) values depending on pressure is different for windows of different systems. For the purpose of comparison the a(p) values were normalized to "0". Figure 12 shows averaged values of such normalized curves obtained for windows from investigated systems. Systems are denoted by numbers, in each of them 6 to 8 windows were considered when averaging. The systems for which the increase of a(p) value together with pressure is evident (steep curves) show better acoustic performance than systems characterized by flat curves (No 3, 5, 6 in the figure).

The considerable increase of a(p) value means that weatherstrips more easily open under air pressure so it can be said that the connection is more "pliable". These observations confirm that the stiffness of the casement supporting gaskets influence the sound insulation of windows.

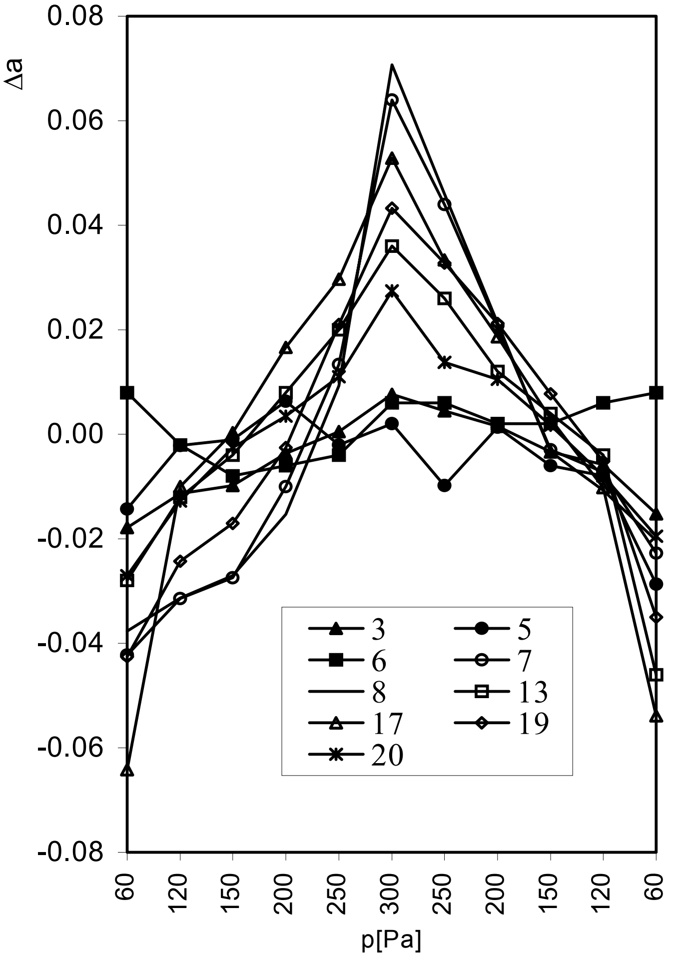

Figure 12. Averaged values of air permeability coefficient normalized to 0 for windows from analyzed systems No 3, 5, 7...

9. CONCLUSIONS

The sound insulation of PVC windows with the same typically used 4/16/4 glazing can be different. Review of acoustic test results shows that the weighted sound reduction index R_w ranges from 32 to 39 dB (R_{A2} from 27 dB to 33 dB, when taking into consideration windows with reduced air tightness $R_{A2} = 24 – 33$ dB). Acoustic performance of a window is not only a question of glazing, other technical factors are also important.

In the case of PVC windows, the joint between the frame and casement form rather an additional sealed chamber in the whole cross section of a frame than a staggered gap. The mechanism of sound transmission via the junction is different than in traditional wood windows. Hence, no strict relationship between air permeability coefficient values and sound insulation was found.

A reduction of window air tightness by making a different kind of slot in the sealing system usually causes a drop in sound insulation in the range of (500 – 1600) Hz. It also causes a decrease in single number quantities but the value of such a decrease depends rather on the method of air tightness reduction than on the final value of air permeability coefficient. Using local slots gives better results than continuous gaps on the whole perimeter (ventilation gaskets or micro-openings).

Weatherstrips acting as a casement supporting element influence the sound insulation of window. Within an analysed group, window systems with more “pliable” weatherstrips show better acoustic performance.

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