Sound insulation of PVC windows at negative outdoor temperatures

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Abstract. The PVC windows using experience in the climatic conditions of the Russian Federation shows that their profile elements are subject to temperature deformations under the influence of the temperature gradient of outdoor air and indoor air. This physical phenomenon is observed both in the summer and winter operation period. In this article we study the influence of external air negative temperatures into the sound insulation of PVC windows. The research was performed on a standard PVC window in a climate chamber with acoustic equipment. The PVC window sound insulation measurements were carried out at the following temperatures inside the cold compartment of the climate chamber: +20 °C, 0°C, -5°C, -20°C (at a constant temperature in the warm compartment of the chamber + 20°C). It is established that the reduction of PVC windows sound insulation begins to occur only at outdoor temperatures below 0 °C. The sound insulation of PVC window at an outdoor temperature -20°C is 3 dB lower than the sound insulation of the same window, determined under standard conditions (+20 °C). Obviously, existing methods of calculation of sound insulation of PVC windows it is necessary to adjust in terms of operational ambient temperatures and design features of the windows.

1. Introduction
Currently, the use of modern windows types (especially PVC windows) has significantly increased in civil construction. This trend is primarily related to increasing requirements for energy efficiency of buildings [1,2]. For this purpose it is necessary to use windows with high thermal characteristics and tightness [3,4]. Another important issue, especially for large cities and megacities, is the need to ensure acoustic comfort in the premises [5-7]. This requires the use of windows with high levels of sound insulation. The modern approach to the assignment of window performance characteristics (including air permeability and sound insulation) involves the use of data obtained under standard conditions (at air temperatures of about + 20 °C) [8-10]. In other words, the calculations do not take into account the actual operating conditions of windows. That is, when assigning window characteristics such as breathability and sound insulation, the actual operating conditions of Windows in winter and summer operating conditions, which differ significantly in outdoor temperatures in most countries of the world, are not taken into account.

At the same time, the experience of using PVC windows in the climatic conditions of the Russian Federation shows that they can be subjected to significant temperature deformations during the
operation [11]. Research shows that temperature PVC windows deformations can reach values comparable to those caused by wind loads [12]. Temperature deformations of PVC windows can occur both in the summer operation period as a result of solar radiation (this phenomenon is most evident in the case of using dark-colored PVC profiles), and in the winter operation period (for PVC window profiles of any color) – due to temperature differences in the outdoor and indoor air. A number of studies show that due to temperature deformations of profiles, the tightness of PVC windows decreases, and, as a result, their performance characteristics deteriorate. - resistance to heat transfer, as well as air permeability [13]. These phenomena also lead to a violation of the normalized indicators of thermal protection – the appearance of condensate, ice [14].

In this work, the authors aim to assess the influence of negative outdoor temperatures on the sound insulation of PVC windows. To date, research on this issue has not been carried out and is at the level of theoretical assumptions. The relevance of this issue is associated with the widespread use of large-sized windows in modern mass construction [15], as well as energy-efficient window systems with wide profile elements characterized by increased temperature deformations. Taking into account the already conducted research, the study of this issue will allow us to further comprehensively approach the purpose of the PVC windows performance characteristics for various climatic conditions.

2. Methods
A standard PVC window was selected to investigate the issue under consideration. The window had a casement and a fixed light. The overall dimensions of the window were H × B = 1.4 × 1.2 m. PVC Profile elements had a mounting width of 70 mm. IGU had the formula 4-16-4-14-4.

The research was conducted on the basis of research Center "Facades SPK" NIISF RAACS (Moscow). The study was conducted in a climate chamber. The climate chamber consisted of two compartments – cold and warm. In each of the compartments, a pre-set temperature was maintained – in the warm compartment +20 °C, in the cold compartment from +20 °C to -20 °C. Between the compartments was a insulated partition with an opening in which the test window was installed. Fixing and sealing the window in the opening was performed in accordance with current installation recommendations. To assess the temperature and humidity conditions inside the climate chamber compartments and on the window surfaces, temperature sensors and heat flow sensors were used. To measure the deformations of the window profile elements, hour-type sensors were used. Broadband "white" noise of constant power over the entire measuring frequency range was created inside the cold compartment of the climate chamber using a noise source from the company "Bruel & KJAER". The sound pressure level inside the cold, warm chamber compartment was measured using a noise analyzer "Bruel & KJAER". Measurements of PVC windows sound insulation were carried out only after stabilization of window profile elements temperature deformations and the stationary mode onset of heat transfer through the window. Measurements were made in the frequency range from 100 to 3150 Hz. The window sound insulation rating was determined in each frequency range as the difference in the average sound pressure levels in the compartments.

The calculation of the window sound insulation \( R_{A\text{tran}} \) (isolation of air noise generated by the urban transport flow) was performed on the basis of the measured values of the frequency air noise insulation characteristic of the window according to the following formula:

\[
R_{A\text{tran}} = 75 - 10 \log \left( \sum_{i=1}^{16} 10^{\frac{1}{10} L_i - R_i} \right) \tag{1}
\]

where \( L_i \) – corrected by the frequency correction curve "A" sound pressure levels of the reference spectrum in the i-th third-octave frequency band, dB;

\( R_i \) – isolation of air noise by this window design in the i-th third-octave frequency band, dB.

The schematic diagram of the test stand for evaluating the windows sound insulation at negative outdoor temperatures is shown in figure 1. The General view of the test stand with the PVC window installed is shown in figure 2.
Figure 1. Schematic diagram of a test stand for evaluating sound insulation of windows at negative outdoor temperatures. 1 – cold compartment; 2 – warm compartment; 3 – insulated partition; 4 – climate system with air temperature control; 5 – test window; 6 – temperature and heat flux sensors; 7 – work station; 8 – linear displacement sensors; 9 – speaker system; 10 – sound level meter.

Figure 2. General view of the test stand with a PVC window installed
3. Results and Discussion
The results of the study are presented in table 1.

Table 1. Results of evaluation of PVC window sound insulation at various outdoor temperatures

| Average geometric frequency of third-octave bands f, Hz | Sound pressure levels adjusted for A, dB | Air noise isolation R(f), dB, at the air temperature in the cold compartment of the climate chamber |
|--------------------------------------------------------|------------------------------------------|-----------------------------------------------------------------------------------------------|
|                                                        |                                          | +20 °C | 0 °C | -5 °C | -20 °C |
| 100                                                    | 55                                       | 25.7   | 27.6 | 26.7 | 27.4 |
| 125                                                    | 55                                       | 19.8   | 20.7 | 17.5 | 20.4 |
| 160                                                    | 56                                       | 25.2   | 22.1 | 24   | 22.2 |
| 200                                                    | 59                                       | 24.7   | 24.7 | 24.6 | 19.7 |
| 250                                                    | 60                                       | 25.9   | 21.7 | 24.9 | 22.1 |
| 315                                                    | 61                                       | 21.5   | 24.1 | 20.5 | 20.9 |
| 400                                                    | 62                                       | 19.7   | 21.4 | 19.3 | 19.0 |
| 500                                                    | 63                                       | 19.8   | 25.4 | 15.9 | 22.1 |
| 630                                                    | 64                                       | 20.6   | 24.5 | 17.3 | 23.6 |
| 800                                                    | 66                                       | 23.9   | 23.8 | 21.9 | 23.4 |
| 1000                                                   | 67                                       | 30.1   | 25.6 | 28.9 | 23.6 |
| 1250                                                   | 66                                       | 36.4   | 29.0 | 36.4 | 23.4 |
| 1600                                                   | 65                                       | 40.1   | 26.6 | 40.2 | 23.6 |
| 2000                                                   | 64                                       | 42.1   | 27.0 | 41.1 | 23.0 |
| 2500                                                   | 62                                       | 39.9   | 26.2 | 37.9 | 21.5 |
| 3150                                                   | 60                                       | 39.2   | 24.4 | 35.6 | 20.3 |

Sound insulation $R_{\text{A}}$, dBA

|                                                        | 25 | 25 | 23 | 22 |

It is established that the decrease in PVC windows sound insulation is observed only at negative outdoor temperatures. The decrease in PVC windows sound insulation at negative outdoor temperatures can be explained by the following reasons:

- reducing the tightness of the flaps joining the window frame due to temperature deformations of window profiles and reducing the elasticity of window seals;
- reducing the IGU sound insulation due to deflections of glass and reducing the distance between the glass under the influence of temperature differences.

Based on the conducted research, we can say that the PVC windows sound insulation at negative outdoor temperatures is largely influenced by temperature deformations of their profiles. Therefore, the existing engineering methods for the purpose of windows sound insulation based on the available characteristics of their individual structural elements should be adjusted [16-18]. At the same time, it is obvious that they must take into account the following design windows parameters that affect temperature deformations and tightness under the influence of negative outdoor temperatures:

- overall dimensions of windows;
- number and overall dimensions of casements;
- material and geometry of profile elements of windows;
- the construction of translucent filling, as well as the method of fixing it in the casements and the window frame;
- material and characteristics of window seals, the presence of ventilation valves.
To study each of these factors, it is necessary to conduct additional comprehensive research. Currently, only certain factors affecting the windows sound insulation have been studied [19-22]. At the same time, the influence of acoustic holes on the sound insulation of enclosing structures (including ventilation valves in windows) has been well studied. The phenomena of sound transmission through open ventilation valves and slits in windows can be considered similar. Therefore, by determining the temperature deformations of window profiles and window seals under the influence of negative outdoor temperatures (and, accordingly, the size of the resulting cracks), you can evaluate the change in windows sound insulation. It should be noted that currently, methods for determining the windows sound insulation at negative outdoor temperatures in laboratory conditions have not yet been developed and tested. This paper is the first attempt to conduct such research. The method developed in this paper can only be used for evaluating the windows sound insulation at negative outdoor temperatures. Currently, the author's team is improving the methodology proposed in the work, as well as conducting comprehensive research on the influence of the above parameters of windows structural elements on sound insulation at negative outdoor temperatures. It seems appropriate to conduct computer simulation of windows at negative outdoor temperatures to determine not only their sound insulation, but also resistance to heat transfer and air permeability. Such multiphysical calculations of windows are currently performed in a limited volume due to the complexity of setting the design scheme of windows, including taking into account the joint work of the frame and sash elements [23], the characteristics of materials (such as PVC) that depend on the outdoor temperature, and other factors.

4. Conclusions

Based on the research conducted in this work, we can draw the following conclusions:

1. Sound insulation of PVC windows decreases as the outdoor temperature decreases. The decrease in sound insulation of PVC windows begins to be observed only at outdoor temperatures below 0 °C. Studies have shown that the sound insulation of PVC windows at an outdoor temperature of -20 °C is 3 dB lower than at the standard test temperature (+20 °C).

2. Existing methods of laboratory determination and engineering methods for calculating windows should be further developed. In this case, it is necessary to take into account not only the operating temperature of the outdoor air, but also the windows technical parameters that affect their deformation characteristics and ensure their tightness.

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