Influence Of Sashes Stiffness On PVC Windows Resistance To Wind Load

A Konstantinov[1] and M Motina[1]

[1]Moscow State University of Civil engineering, Yaroslavskoe shosse, 26, Moscow, 129337, Russia

E-mail: apkonst@yandex.ru

Abstract. Nowadays, the calculation of wind load on PVC window units is carried out according to a simplified method, without taking into account the stiffness of PVC profile elements and the joint actions of their load-bearing elements (imposts) and sashes. The introduction of a refined methodology for the calculation of PVC window units, concerning the above factors, will reduce specific consumption of materials and the cost of products. In this work, we do research about this issue. Laboratory tests were conducted on typical designs of PVC window units to test the effect of wind loads. Various configurations of PVC window units (with different types of reinforcing profiles of sashes and imposts, fixed window, etc.) were examined under different wind pressures. The test results were compared with the theoretical calculations. It is established that the effect of the sash on the deflection of the calculated elements of the window unit is significant, and the theoretical calculations do not coincide with the test results. The model of the PVC window unit operation is described under the action of positive and negative wind pressure, taking into account its components - PVC profiles, reinforcing profiles, insulating glass units, etc. The directions of further research of this issue are suggested.

1. Introduction

Nowadays, mainly PVC window units are used for glazing multi-storey residential buildings of mass construction. Their wide application is first of all due to their lower cost and higher thermal characteristics in comparison with window units made of aluminum profiles or wood [1]. Resistance to wind loads is one of the key performance characteristics of window units. On resistance depends both the retention of the window units' functionality under the effect of wind pressure, and the provision of design indices of the microclimate of the premises (no drafts) and thermal protection of buildings [2-7] (for example, the absence of cold street air infiltration and under the influence of wind pressure) throughout the life cycle of the object.

The main parameter that determines the resistance of window units to wind loads is the stiffness of their load-bearing elements is vertical (horizontal) imposts. According to [8] it is assumed that for PVC window units the stiffness of the imposts is provided only due to the steel reinforcement profiles. At the same time, the constructive solution of PVC window systems implies the use of a modern window hardware that allows the fixing of the opening sashes in the window frame along the entire perimeter, which partially ensures the joint operation of the sashes and the impost under the action of the wind load. Research of the combined action of window sashes and imposts of PVC window units under the influence of wind load have not been conducted yet [9]. Creating an engineering method for

calculating the effect of wind loads on PVC window units, taking into account their design features, has also not being conducted. However, their development and introduction in the practice of engineering PVC window units will significantly reduce the cost of production in typical PVC windows used in multi-storey residential buildings of mass construction.

2. Analysis of the existing method for calculating PVC window units for the action of wind load

According to [8] the calculation of effect of wind load on window units can be made using the engineering method. This method of calculation is universal and allows the calculation of window units made of any material.

This method of calculation is based on the following prerequisites:

- the frame of the window unit is securely fixed along the entire perimeter of the window aperture;
- the vertical (horizontal) impost is the main design element of the window unit. The design scheme of the impost is a beam on two pinned supports, loaded with a trapezoidal load. It is assumed that the wind load distribution on the area of the window unit occurs evenly between the frame and the impost, according to the scheme in Figure 1;
- the criterion for calculating the impost under the action of the wind load is the limit deflection, which ensures that the window unit does not blow out (cold air infiltration during the winter operation period).

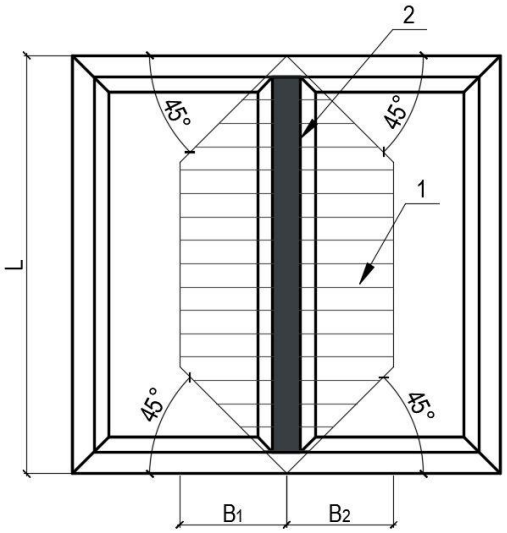


Figure 1. Calculation scheme of the window unit according to [8].
1 - load strip, cm; 2 - calculated element

Calculation of window units for the action of wind load is to determine the design moment of inertia of the impost, which ensures compliance with its design deflection under the action of wind load. The selection of the required moment of inertia of the design impost of the window unit can be made by the formula 1.

$$J_r = \frac{W \cdot L^4 \cdot B}{1920 \cdot E \cdot f}\left[25\text{-}40\left(\frac{B}{L}\right)^2 + 16\left(\frac{B}{L}\right)^4\right] \quad (1)$$

where W - the design value of the wind load, N/sq.mm; B - width of the load strip in the loading epure, cm; L - working length of the mullion, cm; E - modulus of elasticity, N/sq.mm; f - limit deflection of the impost, cm.

At the same time, for each load summary strip, the calculation according to this formula must be made separately. The total required moment of inertia of the impost is defined as the sum of the required moments of inertia of the impost calculated for each load strip (the adding of the widths of the load strips in the formula is not allowed). In the case of calculating PVC window units, the selection of the real moment of inertia of the impost reduces to determining the moment of inertia of

the steel reinforcing profile. At the same time, the stiffness of the PVC profiles of the impost, the joint work of the profiles of the impost and the sashes, the effect of the stiffness of the insulating glass units, and a number of other design features of modern PVC window systems, are not taken into account when selecting the actual moment of inertia of the impost.

Therefore, the calculation of effect of wind load on window units is currently carried out using a simplified engineering method. Laboratory researches of PVC window units also show that this method of calculation has an excess stock of [10]. It is obvious that the existing calculation methodology should be optimized, which requires both carrying out laboratory researches of the most common standard sizes of window units and developing a model for the operation of PVC window units under the action of a wind load.

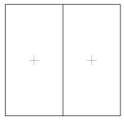
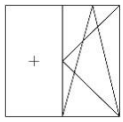
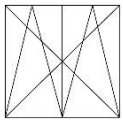
3. Laboratory experiments to research the influence of the sash stiffness on the wind resistance of PVC window units

Laboratory experiments were carried out on the standard design of a window unit, which is currently used in multi-storey residential buildings of mass construction. The overall dimensions of the window unit were 1420 mm (height) and 1450 mm (width) and conformed to a typical window aperture 1.5 × 1.5 m. For the test, a window unit made of PVC profile with a thickness of 58 mm was selected.

As a part of laboratory researches, 11 series of tests were carried out for the various configurations of the window unit. The tests were carried out in different versions:

- imposts;
- sashes;
- types of translucent filling; Variants of the tested variants of window units are presented in Table 1.

Table 1. Complete sets of tested variants of window units

Serial number	Sketch of the window unit	Reinforcement of the impost, mm	Reinforcing the sashes, mm	Types of translucent filling
1 (11)		1,5 (3)	-	Glass 4 mm
2		1,5	-	IGU 32 mm
5 (7)		1,5 (3)	1,5 /-	IGU 32 mm
6 (8)		1,5 (3)	1,5 [a]/-	IGU 32 mm
4 (10)		1,5 (3)	1,5 /1,5	IGU 32 mm
3 (9)		1,5 (3)	1,5 [a]/1,5	IGU 32 mm

[a] - applied reinforcing profile of the sash

The inclusion in the series of tests of window sashes with reinforced reinforcement is due to the widespread use of laminated profiles in typical construction, the manufacturing technology of which requires the use of similar solutions. The inclusion in the series of tests of the window unit complete sets with reinforced reinforcement of the impost is caused with the widespread use of mass housing construction of high-rise buildings on the upper floors of which, as a rule, reinforced window units are required.

For testing, the window unit was installed in a wooden frame and fixed in it with metal fasteners, taking into account the requirements of [11-14]. Laboratory testing of the window unit was carried out on a universal test bench for determining air permeability, water tightness and resistance to wind load of the company KSchulten, installed in the laboratory of NRU MSUSE. The purpose of laboratory researches for each series of tests was to determine the actual deflections of the vertical impost of the

window unit at different values of the wind pressure. During the research, the window unit was exposed to both positive (in the range 0 ... + 1000 Pa) and negative (in the range -1000 ... 0 Pa) values of wind pressure. The step of changing the wind pressure was 100 Pa. The deflection was measured by means of electronic displacement sensors. The arrangement of the displacement sensors was in accordance with the recommendations of [15]. The general view of the test stand with the installed sample of the window unit is shown in Figure 2.

Figure 2. General view of the test stand.
1 - wooden frame; 2 - window unit; 3 - displacement sensor

The results of experiments for series 1-6 and series 7-11 are presented in Figures 3 and 4, respectively.

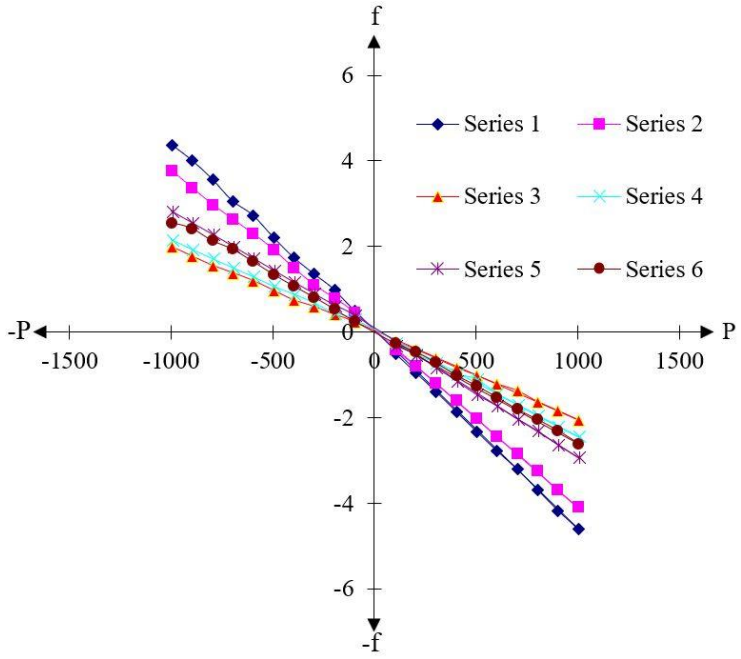


Figure 3. Deflections of the impost for the series of tests 1-6.
+ P - positive wind pressure, Pa; -P - negative wind pressure;
f - positive deflection, mm; - f - negative deflection, mm.

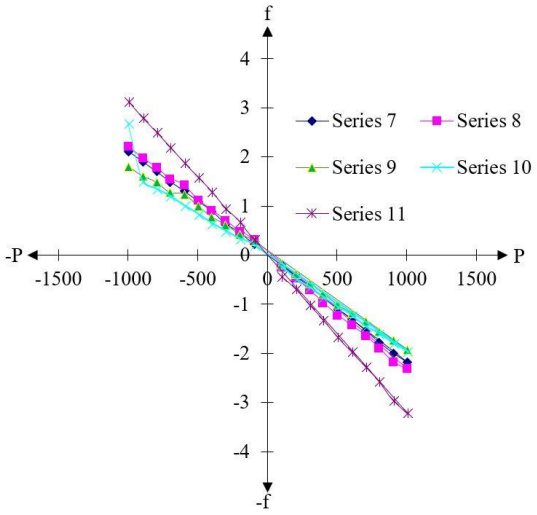


Figure 4. Deflections of the impost for the series of tests 7-11.
+ P - positive wind pressure, Pa; -P - negative wind pressure;
f - positive deflection, mm; - f - negative deflection, mm.

4. Analysis of results. Comparison of the results of experimental researches with theoretical calculations

During the experiments the following was established. The type of translucent filling used has a significant influence on the deflections of the impost under the action of the wind load. The results of the series of experiments No. 1 and No. 3 show that when using insulating glass units with a total thickness of 32 mm, the deflection of the impost was on average 16% lower than when using a 4 mm thick sheet glass. The type of the reinforcing profile of the sashes does not have a significant effect on the operation of the PVC window unit under the action of the wind load. The results of the experiments show that this is true for double-sash (series 6 and 10, 7 and 11) and combined window units - with one opening sash (4 and 8, 5 and 9). The average deviation between the absolute values of deflections for the series of tests indicated in brackets was 16% and 11%, respectively. This is due to the difference in the stiffness of the reinforcing sash profiles in a plane perpendicular to the action of the wind load (the practical moments of inertia differ by 17%).

The main structural element affecting the deflection of the impost is its reinforcing profile. At the same time, it was established that the existing calculation methodology does not substantially correlate with the experimental data (series 1 and 11). According to [8] , the theoretical calculation of the window unit for the action of the wind load must be made proceeding from the limiting deflection of the impost equal to 1/300 of its calculated length. For the tested window unit it will be 0.47 cm. Near to the calculated deflection was achieved in series 1 with an actual wind pressure of 1000 Pa. At the same time, theoretical calculations showed that a similar deflection for the window unit used in series 1 should be achieved already at a pressure of 600 Pa. The results of the experiments obtained in other series of tests showed an even greater discrepancy between the calculated method and experimental research data.

5. The model of the operation on effect of wind loads on the PVC window units

The carried out experimental researches allow to describe the following model of operation of PVC window units under action of a wind load. In this case, we confine ourselves to window units with the opening of the sashes to the interior as the most common in the territory of the Russian Federation and European countries.

Currently, PVC window units are equipped with modern window hardware, which provides multi-point fixing of the sashes to the frame and the impost. The presence of these links in many respects causes the operation of PVC window units under the effect of wind load. We assume that the wind

load is evenly distributed over the area of the window block. In this case, due to the mechanical fixing of the fittings, the wind load collected on the sashes is transferred to the impost (frame) of the window unit. In this case, under the action of positive and negative wind pressure, the operation of PVC window units will occur in different ways. Under the action of positive wind pressure, the transmission of wind load to the impost (frame) of the window unit will occur exclusively through the elements of the window hardware. In this case, the location of the load transfer points will depend on the configuration of the window hardware (locations and number of locking points) (see Figure 5a)). Under the action of negative wind pressure, the sashes will be pressed against the impost (frame) of the window unit. In this case, the transfer of load from the sashes to the impost (frame) will occur both through the locking points and along the perimeter of the sashes (see Figure 5b). The perception of wind loads by imposts and the frame of PVC window frames is due to the joint operation of PVC profiles and steel reinforcing profiles. Transfer of wind load from the window frame to the outer wall will occur through the assembling plates (fasteners).

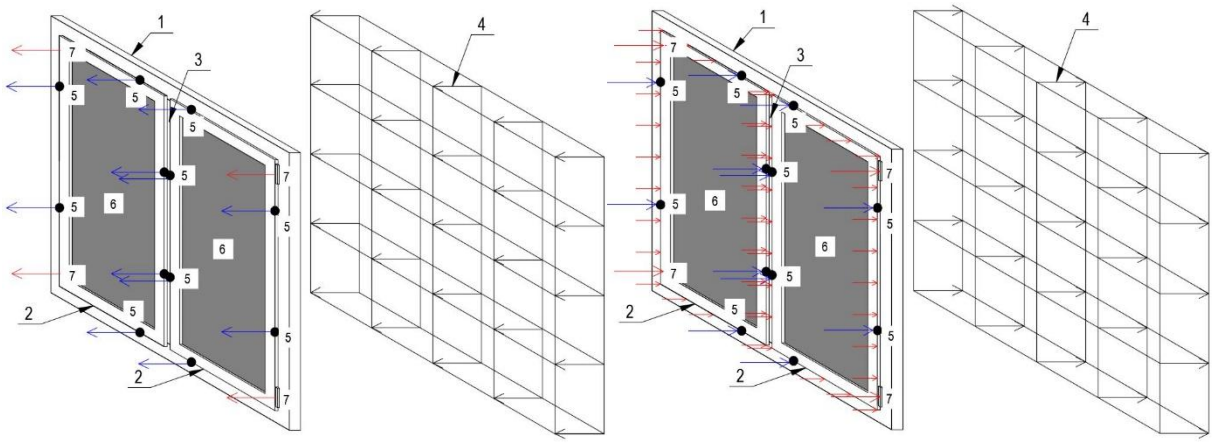


Figure 5. Scheme of operation of the window unit under the action of wind load. a) - with positive wind pressure; b) - with negative wind pressure. 1 - frame; 2 - sash; 3 - impost; 4 - wind pressure; 5 – striker plate; 6 - insulating glass unit; 7 - hinge

6. Discussion

The existing methodology for calculating the effect of wind load on window units, in addition to taking into account the above-described factors, also requires further development in the following areas:

- substantiation of the calculated value of the wind load [16-23];
- substantiation of the calculated deflections of the imposts.

This is due to the fact that at present, due to the lack of necessary researches in Russian regulatory documents, there are no unambiguously defined criteria for determining these quantities. This concerns both the main criterion of calculation - the maximum deflection of the calculated elements of the window unit under the action of the wind load, and the magnitude of the estimated wind load. Conducting these researches will significantly streamline the process of designing window structures.

Until now, the issue of calculating fasteners for the effect of wind load remains unaccounted for. Obviously, in the existing conditions - in the mass construction of multi-storey residential buildings (up to 75 m) and high-rise residential buildings, the use of large-format window units, and the use of energy-efficient technologies for installing window units in the outer wall insulation zone - this question requires special attention. It is necessary to conduct additional researches to develop a methodology for calculating the fixing elements of window blocks for the effect of both wind and operational loads.

7. Conclusions

Experimental researches of the effect of positive and negative wind pressure (in the range of -1000 ... + 1000 Pa) on various PVC window constructions were carried out. It is established that the results of the experiments do not coincide with the data of calculations performed in accordance with the engineering method laid down in the current regulatory documents. The existing methodology for calculating window units is simplified, has an excessive stock and does not fully reflect the actual operation of PVC window units under the action of wind loads. In work considers and analyzes the factors affecting the operation of PVC window units under the action of wind load. A new model for the operation of the PVC window unit under the action of a wind load is proposed. Further directions of research are considered, carrying out of which will allow creating a comprehensive methodology for calculating window blocks for the effect of wind load.

8. References

[1] Boriskina I V, Plotnikov A A and Zaharov A V 2008 *Design of modern window systems for civil buildings* (St. Petersburg: Vybor) p 320
[2] Boriskina I V 2012 *Buildings and Structures with Translucent Facades and Roofs. Theoretical Bases of Designing of Glass Constructions* (St. Petersburg: Lyubavich) p 396
[3] DIN 18055:2014-11 *Criteria for the use of windows and exterior doors in accordance with DIN EN 14351-1*
[4] DIN EN 14351-1:2016-12 *Windows and doors - Product standard, performance characteristics - Part 1: Windows and external pedestrian doorsets; German version EN 14351-1:2006+A2:2016*
[5] SP 54.13330.2016 *Multicompartment residential buildings*
[6] SP 50.13330.2012 *Thermal performance of the buildings*
[7] Gagarin V and Kozlov V 2011 *Vestnik MGSU* **3**(1) 192-200
[8] GOST R 56926-2016 *Window and balcony constructions of different functional purpose for residential buildings. General specifications*
[9] Konstantinov A P 2018 *Science prospects* **1**(100) pp 26-31
[10] Konstantinov A and Lambias Ratnayake M 2018 *E3S Web of Conferences* 33, 02025
[11] GOST 30791-2012 *Erection to joints of window assemblies adjoined to wall openings. General specifications*
[12] GOST 30674-99 *Windows of polyvinylchloride profiles. Specifications*
[13] GOST 23166-99 *Windows. General specifications*
[14] *Guideline for installation of windows and external pedestrian doors* 2016 (Rosenheim: ift Rosenheim) p 251
[15] DIN EN 12211:2016-10 *Windows and doors - Resistance to wind load - Test method; German version EN 12211:2016*
[16] Barshteyn M F 1978 *Guidance on the calculation of buildings and structures to the action of the wind* (Moscow: Stroyizdat) p 120
[17] Savitskiy G A 1972 *Wind load on structures* (Moscow: Stroyizdat) p 112
[18] Simiu E and Skanlan R *Wind effects on structures* (Moscow: Stroyizdat) p 360
[19] Cook N J 1990 *The designer's guide to wind loading of building structures* Part 2 (London: Butterwords) p 20
[20] Birbrayer A N 2008 *Dynamics of buildings and structures. Wind effects on structures* (St. Petersburg: Polytechnic University Publishing House) p 113
[21] Povzun A O, Buzun N I and Zimin S S 2015 *Construction of Unique Buildings and Structures* **3**(30) pp 70-80
[22] EN 1991-1-4:2005+A1:2010 *Eurocode 1 Actions on structures. General actions. Wind actions*
[23] SP 20.13330.2016 *Loads and actions*