Assessment of the Wind and Temperature Loads Influence on the PVC Windows Deformation

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Abstract. The PVC windows application experience in various climatic conditions shows that at their operation the windows profile deformations can be observed. One of the reasons for these deformations is the climatic loads influence on the windows – wind pressure, solar radiation, negative outside temperatures. The profile elements deformations affect the window tightness and the normal window hardware operation. The calculated loads combinations on windows in winter and summer were analyzed. For window as external element of building is more critical winter loads combination – the combined effect of wind pressure and negative temperature. The work was done the analysis of the effect of negative temperatures and wind pressure on the PVC window deformation. The studies were performed in laboratory conditions on the basis of two testing centers. Three PVC Windows with different profile thickness were tested. The temperature deformation of the casements and mullions profiles of this windows were analyzed. These deformations have to take into account in the static calculations. But the engineering methods creation for calculating windows for the wind and temperature loads effect requires additional research. They are associated with the study of the joint work of the windows constituent elements (profiles, insulating glass units, hardware).

1. Introduction

Nowadays, PVC windows are widely used in building around the world [1]. Due to the current trends in increasing the requirements for the buildings energy efficiency (and accordingly the thermal characteristics of their external elements) for the PVC windows manufacture used multi-chamber PVC profiles.

Now in mass construction are widely used PVC window profiles with composite structure (PVC and steel profile) [2]. The steel profile serves for perception of the loads acting on a window (due to low durability and high thermal expansion coefficient of PVC). For modern PVC profiles is characterized by an asymmetrical arrangement of steel profile (closer to the inner surface of the PVC profile). Increasing the PVC window profiles thermal characteristics is achieved by increasing the air chambers number, and, accordingly, the total profiles thickness. In PVC profiles with high thermal performance, this asymmetry is more pronounced (see figure 1). This can lead to significant deformations of non-reinforced profiles parts under the action of the temperature difference on the outer and inner window profiles surfaces. These temperature differences occur due to the heating of the outer surface of the window profiles under the solar radiation action (in the summer), as well as the

cooling of the outer profiles surface under the action of negative outdoor temperatures (in the winter) [3-5].

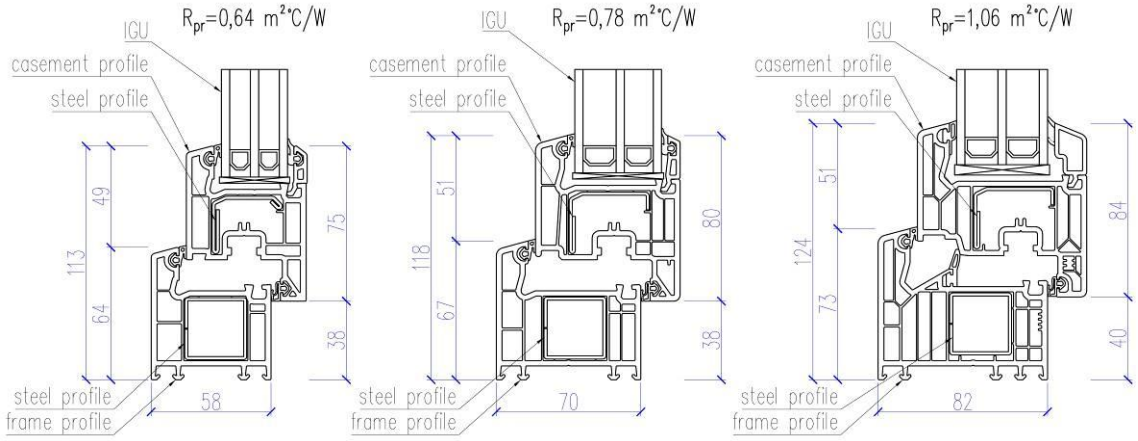

Figure 1. Cross-sections of the profile combination "frame + casement" and thermal performances of PVC windows with different thickness profiles.

In the existing engineering practice, PVC Windows static calculations do only on the wind load action [6,7]. Windows calculation on the temperature loads action, as a rule, is not done. The constructive measures used in practice, regulated by the PVC profile systems manufacturers, are aimed primarily at the perception of windows temperature deformations in their plane (i.e. increase / decrease in overall dimensions). But the use of modern PVC Windows in different climatic regions of Russia shows that during their operation there are significant thermal deformation in another windows plane (torsion and bending profile elements). These deformations have a negative impact on the possibility of opening / closing the window casements and also lead to a decrease in their thermal characteristics (increased air permeability, lower temperatures on the inner window profiles surfaces). To exclude such phenomena in the engineering practice of PVC Windows design, it is necessary to introduce new static calculation methods, based not only on the account of wind, but also temperature loads [8].

The problem of temperature deformations of windows was studied by some researchers [4-6,9-12]. The substantiation of the theoretical model of the window profile elements deformations under the action of negative temperatures and solar radiation was performed [4-6]. On the basis of numerical calculation in two-dimensional statement of the stress-strain state of PVC windows the size assessment of temperature deformations for some types of PVC window profiles was done [9]. But the study of the wind and temperature loads influence on PVC windows with different profile thickness and their comparison is not done yet. Therefore, the aim of this work is to assessment the profile elements deformations of modern PVC Windows under the action of wind load and temperature difference of external and internal air for winter operating conditions.

2. Justification of the calculated combination of temperature and wind load on the window profile elements

Windows and their individual structural elements (profiles, insulating glass units and etc.) are exposed to various loads combinations during their operation. For each of the window structural elements this combination will be different. It will depend on the climatic conditions of operation [13,14] (for example, for insulating glass unit - on the air temperature and pressure changes), the constructive window solution, but also the window operating mode (for example, window fasteners should be designed to accept loads from the window both in the open and closed position of the casements).

The calculated loads combination on the window profiles will be different for open and closed windows. Further, only the case with a closed window will be considered. In the closed position the

window has to carry out all protecting functions assigned to it, including and provide tightness. In this case, in general, the profile elements can be affected by the following loads:
- own weight of profiles and insulating glass units;
- wind pressure (both positive and negative);
- temperature loads from the temperature difference on the outer and inner profile elements surface.

The temperature on the outer surface of the profile elements depends on the temperature of the outside air and the solar radiation intensity.

We will consider only Windows with casements opening indoors (they are the most widespread in the countries of Western Europe and Russia). For this windows type the most unfavorable loads combination on profile elements is (see figure 2):
- combination 1 (based on summer operating conditions). The sum of the negative wind pressure and temperature load from the temperature difference on the outer and inner profile surface by the action of the solar radiation and elevated outside air temperatures.
- combination 2 (based on winter operating conditions). The sum of the positive wind pressure and temperature load caused by the temperature difference on the outer and inner profile surfaces (excluding solar radiation, i.e. in the dark).

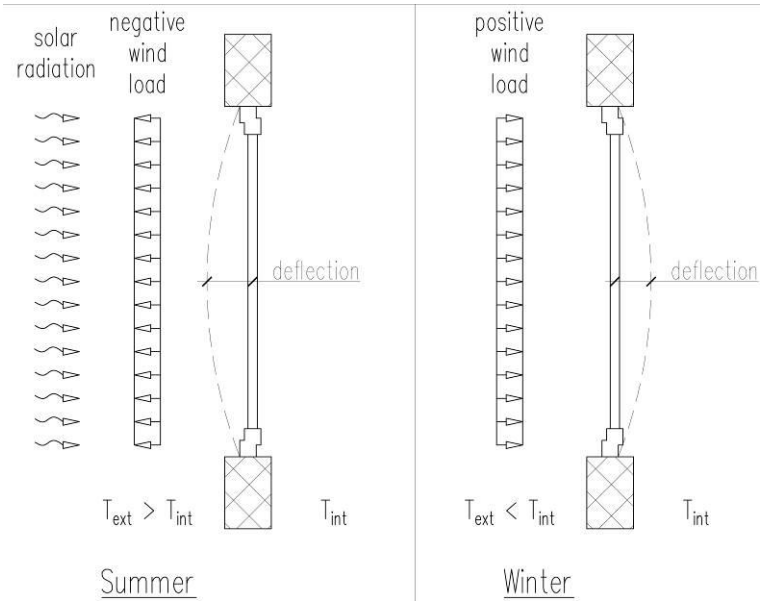

Figure 2. Diagram of the window mullions deflection under adverse wind and temperature loads combinations.

These loads combinations will be calculated, because only in these cases, the profile elements movement from each load type will occur in one direction and be summed. The calculation of the windows static characteristics is currently done on the wind load action from the condition of the appearance of infiltration of cold air into the room. I. e. at the same time the operation winter conditions are considered. Therefore, below we consider only the second loads combination.

3. Laboratory testing method of PVC windows on the wind and temperature loads action

Three double-casement PVC windows of the same overall dimensions, but with different profile thickness (58 mm, 70 mm, 82 mm) were selected for testing. The overall dimensions of each window were H x W = 1400 x 1200 mm. Each window had a vertical mullion in the middle and one casement. All windows were made of white PVC profiles. Reinforcing steel profiles in all windows were the same.

The study of PVC windows was carried out on the basis of two test centers:
- Research Center "Facades SPK" NIISF RAACS (Moscow).
- Testing laboratory "Translucent structures and facade systems" (NRU MGSU) (Moscow).

Research in the center "Facades SPK" was carried out in two stages. At the first stage the profile elements deformations of PVC Windows under the influence of wind load were determined. For this the test stand for windows was used (to determine the air-, water permeability and wind load resistance). At the second stage the profiles elements deformations of PVC windows under the temperature loads influence were determined in the climatic chamber.

Before the tests the windows were mounted in a wooden frame. The windows installation was carried out taking into account requirements of existing standards [15].

The profile elements deformations of PVC windows under the wind load influence were measured at wind pressure from +100 to +1500 Pa. The profile strain measurements were carried out using electronic linear displacement sensors. After the wind load test, the window was transferred to the climate chamber.

The climate chamber consisted of two compartments – cold and warm. A heat-insulating partition with the window opening was installed between the compartments (see figures 3,4). After mounting the window, it was installed sensors of two types:

- linear displacement sensors for measuring the profiles deformations;
- contact type temperature sensors for measuring the temperature on the profile surfaces.

In the warm compartment is constantly maintained temperature +20 °C. In the cold compartment temperature was variable and dropped in steps to temperatures -5°C, -15°C, -25°C, -35°C and -45°C.

The measurements of the profile deformations at each stage of temperature change in the cold compartment was carried out only when installing stationary temperature conditions.

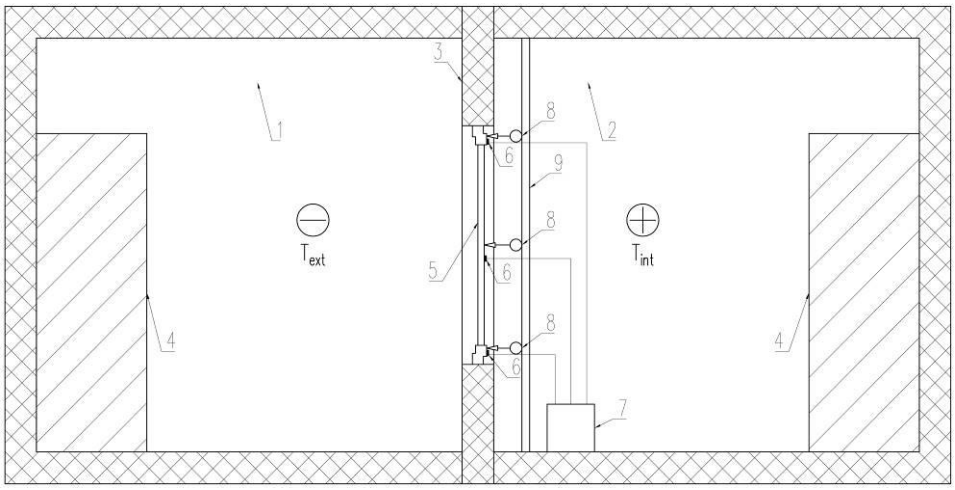

Figure 3. The schematic diagram of the test chamber to determine the windows deformation under the temperature influence. 1 – cold compartment; 2 – warm compartment; 3 – insulated partition; 4 – climate system with air temperature control; 5 – test window; 6 – temperature and heat flux sensors; 7 – work station; 8 – linear displacement sensors; 9 – support.

Research on the basis of the testing laboratory "Translucent structures and facade systems" was conducted to assess the PVC Windows deformation in the combined action of wind pressure and thermal loads. These studies were conducted only on the PVC window with a frame thickness of 58 mm. The test stand was a standard stand for determining the air, water permeability and resistance to wind load, but equipped with the climate system. For the experiment was fabricated timber frame insulated wall. The wall has an opening for the windows installation. The use of an additional partition is due to the design features of the stand. After installing the window into the partition, two types of sensors were installed (see figure 5):

- linear displacement sensors for measuring the mullion deflection;
- contact type temperature sensors for measuring the temperature on the profiles surfaces.

In the experiment course in the cold stand compartment was installed the negative air temperature -20 °C. Inside the room was a constant temperature of +20 °C. Tests on the combined effect of wind and temperature load was carried out only with the installation of stationary temperature conditions.

During the experiment, the window was tested under the above temperature conditions at pressure drops, respectively, +500 Pa, +750 Pa and +1000 Pa. After the measurement of the deformation of the mullion profile at each test pressure stage, the test was stopped before the onset of the stationary temperature conditions.

Figure 4. General view of the PVC window installed in the climatic chamber for testing the temperature load.

Figure 5. General view of the PVC window installed in the test stand for the combined wind and temperature load action.

4. Results. Analysis of experimental data

Laboratory studies of PVC windows showed the following results:

1. The temperature deformation of PVC windows mullions is comparable in magnitude to the deformation from the wind loads action (see figure 6). Therefore, when carrying out static PVC windows calculations, it is necessary to take into account the temperature deformation of their profiles.

2. Under the wind and temperature loads action the frame and casement profiles get deformations comparable to the mullion profiles deformations (figure 7). This is due to the fact that in modern PVC Windows used hardware, providing multi-point fastening of the casement around their perimeter to the frames and mullions. At the same time, this fastening is not absolutely rigid and allows the window elements to deform independently of each other. It should also be noted that the casement deformation value under the temperature loads influence is less than that of the mullion profiles. This is due to the fact that when exposed to negative temperatures, the casement profiles are in a warm zone (closer to the room). Currently, static calculations of the casement profiles, as a rule, are not carried out [16]. But the results show the need for such calculations, because it will minimize the negative impact of these loads on the tightness loss of windows.

3. Deformations of PVC window profiles under the temperature loads action are the higher, the greater the profiles width (see table 1). I.e. temperature deformations are determined primarily by the PVC profiles configuration.

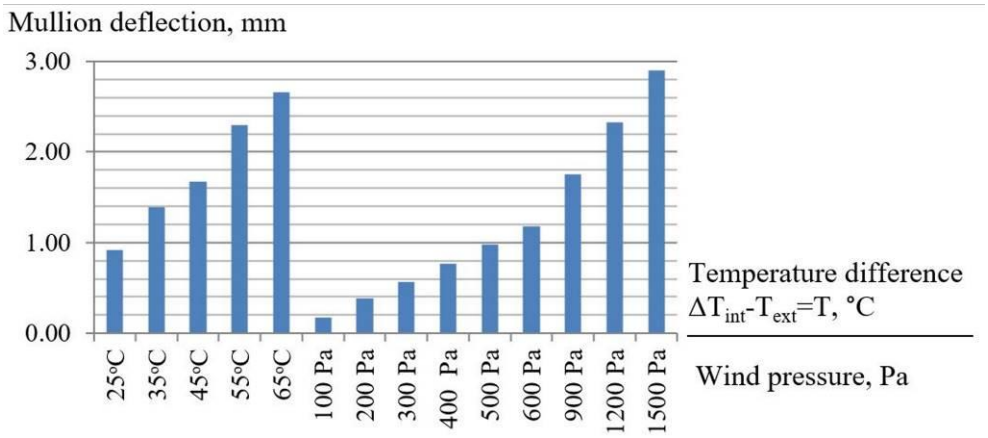

Figure 6. The mullion profile deformation comparison of the PVC window (with the thickness of 70 mm profiles) under the action of wind and temperature loads.

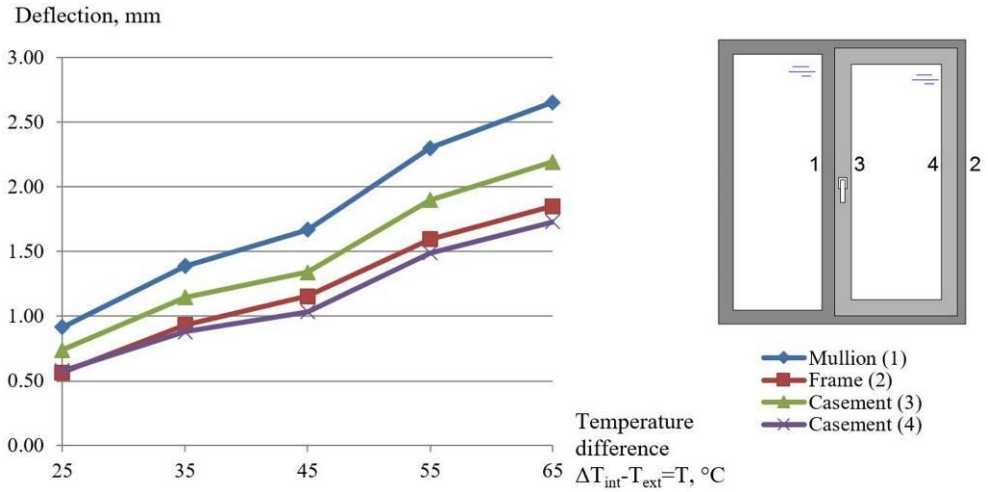

Figure 7. The deformation comparison of the mullion, frame and casement profiles of PVC window (with the thickness of 70 mm profiles) under the temperature loads action.

Table 1. Temperature deformations of PVC mullion profiles with different thickness.

Profile thickness	Temperature deformation of the mullion, mm, at outside air temperature				
	-5 °C	-15 °C	-25 °C	-35 °C	-45 °C
58	1,07	1,41	2,02	2,54	2,89
70	0,92	1,39	1,67	2,30	2,66
82	1,35	1,93	2,38	3,18	3,67

Comparable in size temperature deformation of PVC windows with the thickness of profiles 58 and 70 mm can be explained by much lower rigidity of the insulating glass units installed in PVC window with the thickness of profiles 58 mm (32 mm against 42 mm in a window with the thickness of profiles 70 mm).

4. Studies of the combined effect of temperature and wind loads on the PVC window sample with a frame thickness of 58 mm showed that the mullion deflection under these loads can not be determined as the sum of the deflections from the action of each load separately (see table 2).

Table 2. Mullion deflection under the joint action of wind and thermal loads (the window thickness of the profile is 58 mm).

Mullion deflection from the wind load action		The average mullion deflection from the temperature load action at a temperature difference 20-(-20)=40 °C, mm	Mullion deflection from the combined action of wind and temperature loads, mm
Wind load, Pa	Deflection, mm		
500	0,73	1,62	1,38
750	1,15		2,12
1000	1,49		2,85

5. Discussion

Research have shown that temperature load (from the temperature difference of the external and internal air) have a significant impact on the PVC window profiles deformation.

In static calculations of PVC windows, it is necessary to take into account the deformation caused by the combined action of wind and temperature loads. But the introduction of such calculations in current practice is constrained by a number of restrictions:

- strong dependence of strength and deformation characteristics of PVC on operating air temperatures [2];
- uneven temperature distribution over the thickness of PVC profiles (due to the presence of closed air chambers and technological holes in the profiles);
- the use of modern hardware in PVC windows, which ensures the fixation of casement profiles along the entire perimeter to the window frame and mullion. The location and number of the locking mechanisms of the hardware is determined by the technological capabilities of the manufacturers of the fittings and depends on the casement dimensions. The hardware determines the scheme of fixing the casement in the window and, accordingly, their deformations;
- the influence of the insulating glass unit rigidity on the casement and frame profiles deformation;
- etc.

For the development of engineering methods for calculating windows, which take into account the complex features of their design and the loads acting on them, additional research needs to be carried out in the future.

Laboratory tests for the combined effect of wind and temperature loads are associated with technical difficulties in supplying cold air with the necessary temperature to create a pressure drop. Existing standard test stands do not allow such tests.

6. Conclusions

On the basis of several test centers, laboratory research of modern PVC Windows with different thickness profiles (58 mm, 70 mm and 82 mm) for the temperature and wind loads action were done.

The research has shown the following results:

1. Temperature deformations of PVC window mullions are comparable in magnitude with their deformations due to the action of wind loads.

2. Temperature deformations of PVC window profiles are higher, the greater the thickness of the profiles.

3. Under the influence of temperature loads, the casement profiles are also subjected to deformation. The casement profiles deformations magnitude is lower than the deformations of the mullions profiles.

4. The most unfavorable combination of loads on windows in winter is the sum of temperature loads and positive wind pressure. A laboratory experiment showed that mullions profiles deformations

under the action of the specified combination of loads cannot be determined as the sum of the individual deformations from the indicated loads.

5. The introduction of engineering methods for calculating window profiles to the current practice for the combined effect of wind and temperature loads requires additional research.

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