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TEMPERATURE DEFORMATIONS OF PVC WINDOW PROFILES WITH REINFORCEMENT

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Abstract. Modern window structures made of PVC profiles can experience significant temperature deformation during both winter and summer operation. This effect is not considered in the current engineering methods of PVC windows calculation, which causes a number of problems in their operation (freezing and blowing through the windows, the failure of fittings, etc.). The use of laboratory methods of testing windows for temperature loads is limited due to their labor intensity and the high cost of testing equipment. We propose to develop an engineering method for calculating the mechanical operation of PVC windows under the action of temperature loads, which can be used at an early stage of design. One of the stages of its creation is a theoretical description of the temperature deformation of a PVC window profile when it works together mechanically with a reinforcing core. The article describes the nature of the forces transmitted by the PVC profile on the core during thermal bending (the case of temperature deformation at negative outside temperatures is considered). It was proposed to decompose these forces into two components: longitudinal, caused by different values of temperature shrinkage of PVC profile and reinforcing core, and transverse, caused by thermal bending of PVC profile. Mathematical models have been developed to calculate both force components and temperature deformation of the profile at different numbers and spacing of attachment points. A physical model has been proposed for implementation in the numerical calculation program, which allows a more accurate description of the temperature deformation of a long profile. Calculation of the test problem according to the proposed methodology and by means of full-fledged three-dimensional finite-element modeling in the COMSOL Multiphysics program was performed. A comparison of the results showed a discrepancy of less than 10%. It was found that the key influence on the deformations of PVC window profiles with a reinforcing core will have characteristics of the outermost joints "PVC profile – reinforcing core", because the greatest forces arise in them under the action of temperature loads.

Keywords: PVC windows, temperature deformation, finite-element modeling, COMSOL Multiphysics, PVC profiles.

ТЕМПЕРАТУРНЫЕ ДЕФОРМАЦИИ ОКОННЫХ ПРОФИЛЕЙ ПВХ С УЧЕТОМ АРМИРОВАНИЯ

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Аннотация. Современные оконные конструкции из ПВХ профилей могут испытывать значительные температурные деформации как в зимний, так и летний период эксплуатации. Данный эффект не учитывается в действующих инженерных методах расчета окон ПВХ, что становится причиной ряда проблем при их эксплуатации (промерзание и продувание окон, нарушение работы фурнитуры и т.д.). Применение лабораторных методов испытаний окон на действие температурных нагрузок носит ограниченный характер из-за их трудоемкости и высокой стоимости испытательного оборудования. Предлагается к разработке инженерный метод расчета механической работы ПВХ окон при действии температурной нагрузки, который может быть использован на ранней стадии проектирования подобных конструкций. Одним из этапов его создания является теоретическое описание температурных деформаций оконного ПВХ профиля при его совместной механической работе с армирующим сердечником. В статье описан характер усилий, передаваемых ПВХ профилем на сердечник при температурном изгибе (рассмотрен случай температурных деформаций при отрицательных температурах наружного воздуха). Предложено разложить эти усилия на две компоненты: продольную, обусловленную различной величиной температурной усадки ПВХ профиля и армирующего сердечника, и поперечную, обусловленную температурным изгибом ПВХ профиля. Разработаны математические модели, позволяющие рассчитать как обе компоненты усилий, так и температурные деформации профиля при различном количестве и шаге точек крепления. Предложена физическая модель для реализации в программе численного расчета, позволяющая более точно описать температурные деформации профиля большой длины. Выполнен расчет тестовой задачи по предложенной методике и средствами полноценного трехмерного конечно-элементного моделирования в программе COMSOL Multiphysics. Сравнение результатов показало расхождение менее 10%. Установлено, что ключевое влияние на деформации оконных профилей ПВХ с армирующим сердечником будут оказывать характеристики крайних узлов соединения «ПВХ профиль – армирующий сердечник», т.к. именно в них возникают наибольшие усилия при действии температурных нагрузок.

Ключевые слова: ПВХ окна, температурные деформации, конечно-элементное моделирование, COMSOL Multiphysics, ПВХ профили.

1. INTRODUCTION

Currently, the quality assessment of windows is based on the use of declared (nominal) values of their technical and operational characteristics. Nominal technical and operational characteristics of windows are determined under standard laboratory test conditions without reference to the actual climatic conditions of operation [1]. Thus, most standards for test methods of air permeability of windows (EN 1026 in Europe, ASTM E283 – in North America, GOST 26602.2 – in Russia) requires tests at the same and constant temperature on both sides of the window [2–4]. This approach is reasonable and appropriate for the purpose of comparing the products of individual manufacturers with each other. However, this does not correspond to the real operating conditions of windows during the cold season, when their tightness becomes an important factor influencing the quality of the microclimate in the room [5–8]. Temperature loads lead to deformation of the profile elements of the window. This leads to a decrease in the compression force of window seals, which violates the tightness of the window and can increase its air permeability by several times compared with the results of standard tests [9,10]. For the first time this phenomenon was studied in 1970 in the work [11] where it was found experimentally that the air permeability of windows with double vertical sliding sash increases with decreasing outside air temperature.

A very important work in the topic under study is the work [12]. It discusses the disadvantages of the method used in the USA (at the time of 1985 year) for determining the air permeability of window structures (ASTM E283). One of the criticism points is precisely the lack of consideration of temperature loads. The author proposed to develop a new method for testing the air permeability of windows, taking into account the temperature load. This method has been implemented in the new ASTM E1424 – 91 standards, which now runs parallel to ASTM E283. In the Russian Federation, the methodology for determining the air permeability of window structures with regard to temperature effects was patented in 2012 [13], but it has never become mandatory.

Studies on the subject in Western Europe and North America have ceased since the publication of the work [10] in 1998. The work evaluated the effect of changes in the air permeability of windows when the outside temperature decreases on the energy balance of the building. As a result, it was concluded that this phenomenon has an insignificant effect on the energy balance of the building and therefore in the daily design activities it can be neglected. However, these results were obtained at the design temperature of the outside air during the heating period of -5°C, which is acceptable for the countries of Europe, but unacceptable for countries with cold climate [14–16]. In the Russian Federation the problem of temperature deformation of window structures and their impact on air permeability, on the contrary, began to receive attention in recent years. A number of experiments have been conducted, which confirm the conclusions of earlier studies – the air permeability of window structures may increase 3-10 times when the outside air temperature decreases to -30...-50°C [17–20]. The works [21,22] show that temperature deformation of modern PVC and aluminum windows in winter conditions can be comparable to deformations from wind load. In the work [23], which was the result of a large number of laboratory tests, it is proposed to develop a set of criteria for the applicability of windows for different climatic operating conditions, and the temperature deformation are considered in this case as one of the mandatory factors to be taken into account.

Methods of experimental investigation of window temperature deformation, with all their obvious advantages, have significant limitations: the complexity and high cost of the necessary test equipment, significant time and labor costs to conduct tests. Accordingly, it seems appropriate to develop a theoretical method for calculating the temperature deformation of windows, which would allow the engineer to make effective design decisions. To date, only a limited number of papers have attempted to study the temperature deformation of modern windows by analytical or numerical methods. The authors of this paper previously published an article [24] in which they examined in detail the bending process of unreinforced PVC window profile from the action of temperature load, taking into account the actual temperature distribution in its cross section. The present article deals with the joint operation of the PVC profile and the reinforcing core.

2. METHODS

In winter conditions, there are temperature differences on different sides of the window. Its value depends on the climatic region of construction, and in the Russian Federation can reach up to 60°C. As a consequence, the profile elements of the window undergo a bend in the direction of the warm room. The presence of steel reinforcing core significantly affects the nature of deformation of PVC window profile under temperature load. PVC profile is connected to the core by means of self-tapping screws, the number and pitch of self-tapping screws may vary depending on the length of the profile. As it was found out [24], the temperature field arising in the cross section of the steel core is practically homogeneous (due to the large value of the thermal conductivity coefficient of steel [25]). This means that the core experiences only longitudinal temperature deformations and remains straight, while the PVC profile tends to bend. For simplicity, let us assume that the forces between the core and the PVC profile are transmitted only at the joints of the self-tapping screws (in other words, we will not consider the contact interactions, which in the general case may occur in the problem under consideration). Since the stiffness of the reinforcing core is many times greater than the stiffness of the PVC profile, at the first stage we will consider the core as an absolutely rigid body. Let us also neglect the fact that the locations of the self-tapping screws (and, therefore, the forces occurring in them) are eccentric with respect to the neutral axes of the PVC profile and the core, and we will consider these forces to be centrally applied. The forces occurring at the connection points of the profile and the core will have both longitudinal and transverse components (see figure 1). Transverse components are due to the tendency of the PVC profile to bend, they compensate for this bend. The longitudinal components are due to the difference in longitudinal temperature deformations of the profile and the core.

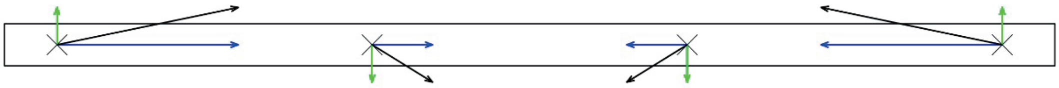

Figure 1 – Forces transmitted from PVC profile to reinforcing core (at 4 attachment points)

To determine the magnitude of these forces, we use the superposition principle. Let us assume that due to the smallness of the deformations of the PVC profile, their longitudinal and transverse components can be found independently of each other.

2.1 Determining the longitudinal force components

Assume that the profile and the reinforcing core experience only longitudinal temperature deformations. We will look for the solution in general form (see Figure 2). Let the PVC profile has an arbitrary length and is connected to the reinforcing core with m fasteners (the distances between the fasteners can also be arbitrary). Each fastener has two points: one referring to the core (we will denote the coordinate of this point by a capital letter *"X"*), the other referring to the PVC profile (we will denote the coordinate of this point by a lowercase letter *"x"*). Initially, the X and x coordinates are the same in each fixture: $X_i = x_i$

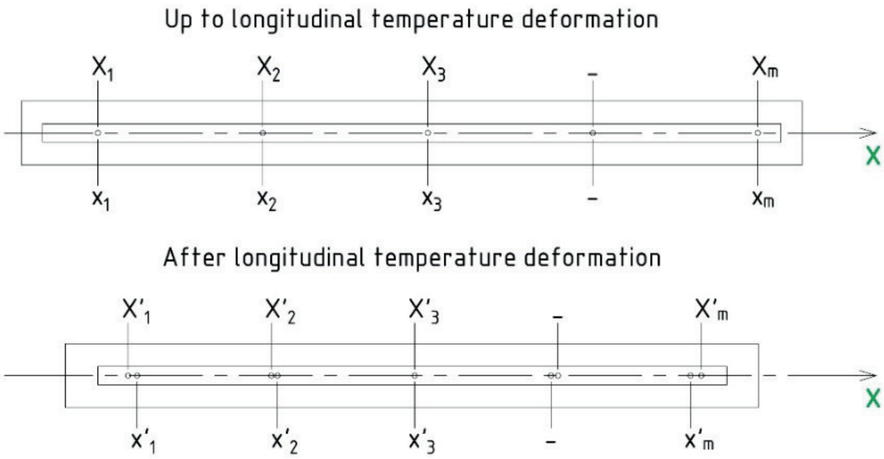

Figure 2. Physical model for determining the longitudinal forces at the attachment points

As a result of temperature stresses, the reinforcing core changes its length (its corresponding attachment points move and occupy a new position *X'*). Since the core is regarded as an absolutely rigid body, then:

$$\begin{aligned} X'_i &= X_i(1+\alpha_s(T_m - T_{ref})) \\ X_1 &= 0 \Rightarrow X'_1 = 0 \end{aligned} \qquad (*)$$

PVC has a much higher coefficient of linear thermal expansion than steel, so when PVC cools down, the profile shrinks much more than the core (in the problem at hand we calculate exactly for winter operating conditions). Free shrinkage of the PVC profile is prevented by the forces generated at the fixing points. The PVC profile is stretched in this process. As a result of the deformation, the attachment points belonging to the PVC profile move from the old position x to the new position x'. At the same time, due to the supposed suppleness of the mount, the points X' and x' belonging to the same mount can move relative to each other, and a force occurs between them $|H_i| = \xi_x \cdot |X'_i - x'_i|$. The conditions described above are mathematically expressed by the following system of equations:

$$\begin{cases} x'_2 - x'_1 = (x_2 - x_1)k_{ax}^{unc}(\dfrac{N_1}{E_{PVC}A} + 1) \\ x'_3 - x'_2 = (x_3 - x_2)k_{ax}^{unc}(\dfrac{N_2}{E_{PVC}A} + 1) \\ \vdots \\ x'_m - x'_{m-1} = (x_m - x_{m-1})k_{ax}^{unc}(\dfrac{N_{m-1}}{E_{PVC}A} + 1) \quad (**) \\ N_1 = \xi_x(x'_1 - X'_1) \\ N_2 - N_1 = \xi_x(x'_2 - X'_2) \\ \vdots \\ N_{m-1} - N_{m-2} = \xi_x(x'_{m-1} - X'_{m-1}) \\ -N_{m-1} = \xi_x(x'_m - X'_m) \end{cases}$$

where $k_{ax}^{unc} = \varepsilon_{ax}^{unc} - 1$ is the coefficient of longitudinal deformation of the PVC profile axis at unconstrained temperature deformation (see [24]) and N_i is the longitudinal force between the i and i+1 attachment points.

Equations (**) with account of (*) form a linear closed system that can be solved by the matrix method. By solving this system, we can find the vector of unknown quantities and determine the magnitude of longitudinal forces arising in the PVC profile.

2.1 Determining the traverse force components

Assume that the PVC profile attachment points to the reinforcing core can slide freely along the core axis. Then, when bending the PVC profile at the connection points only transverse forces will occur. Consider a few cases:

1. PVC profile is connected to the core with 2 self-tapping screws (true for short profiles);
2. PVC profile is connected to the core with 3 self-tapping screws;
3. PVC profile is connected to the core with 4 self-tapping screws;
4. PVC profile is connected to the core with more than 4 self-tapping screws.

2.2.1 Two attachment points

In the first case, no transverse force will occur at the two connection points. PVC profile will curve freely with the curvature K_{unc} (profile curvature at unconstrained temperature deformation – see [24]), the distance between the mounting points will be reduced (because they can freely slide along the core). Now apply a force N to the sliding attachment points, determined by the method described in the previous section. This takes into account that the PVC profile at the same time as bending also experiences tension. After the longitudinal force is applied, the deflection of the PVC rod will decrease. Calculation of deflections, in which the influence of the longitudinal force is taken into account, will give more accurate results, but will also lead to more complex calculation formulas. On the contrary, neglecting the influence of the longitudinal force will result in simpler calculation formulas, but at the same time a less accurate result Table 1 shows a comparison of the analytical solution for bending of the profile axis in two these statements. The calculation scheme of the problem is shown in Figure 3. The calculation takes into account that in the case of small displacements, the curvature of the profile is equal to the second derivative of the deflection function.

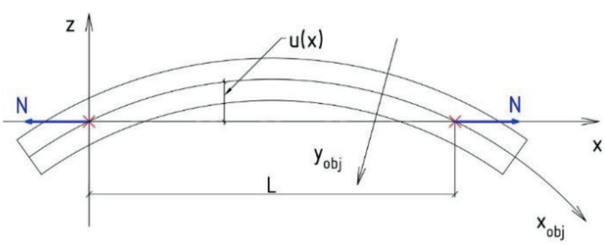

Figure 3 – Calculation scheme

Table 1. Analytical solution for different formulations of the problem

	Taking into account N (1)	Excluding N (2)
The analytical solution	$u(x)=\dfrac{K_{unc}EI}{N}\left(\dfrac{e^{\omega x}+e^{\omega(L-x)}}{1+e^{\omega L}}-1\right)$	$u(x)=\dfrac{K_{unc}}{2}x^2-\dfrac{K_{c\text{в}}L}{2}x$
The maximum deflection	$u_{\text{m}}=-\dfrac{K_{unc}EI}{N}\cdot\dfrac{(1-e^{\frac{\omega L}{2}})^2}{1+e^{\omega L}};\ \omega=\sqrt{\dfrac{N}{EI}}$	$u_{\text{m}}=-\dfrac{K_{unc}L^2}{8}$

The maximum possible step between the screws when attaching the reinforcing core to PVC profiles is determined by the technological recommendations of PVC profile manufacturers, but usually not more than 400 mm. Comparative calculations on specific examples showed that the difference between the values of maximum deflection calculated according to formulas (1) and (2) of Table 1 is the greater the parameter L is. At L = 0.4 m this difference is about 1.5% (the maximum deflection in this case reaches about 1 mm). Such a difference can be neglected and the deflections can be calculated using the simpler formulas (2) in Table 1. Note that if the maximum deflection of the PVC profile is less than the gap that exists between the reinforcing core and the PVC profile, then there will be no contact between them, otherwise the PVC profile will be pressed (central part) into the wall of the reinforcing core and the calculation scheme will change, in the joints there will be transverse forces.

2.2.2 Three attachment points

In the second case, the central fixing point will prevent the free bending of the PVC profile. This will result in balanced lateral forces at the attachment points (see Figure 4).

In the previous example, it was found that the longitudinal force does not significantly affect the deflections of the profile. In this and the following sections of the paper, in addition to deflections, the transverse reaction forces (R) at the attachment points will also be determined. The attachment points of the PVC profile to the reinforcing core may in general also be malleable in the transverse direction. This allows them to shift relative to the center line of attachment. Let us assume that the value of this displacement is proportional to the shear force occurring in the anchorage $|R_i|=\xi_z|u_i|$. To estimate the most significant factors in determining the transverse reaction forces, the problem will be solved in 4 formulations:

1. Without taking into account N / Without taking into account compliance
2. Without taking into account N / Taking into account compliance
3. Taking into account N / Without taking into account compliance
4. Taking into account N / Taking into account compliance

Since the problem is symmetrical, there will be no longitudinal force at the central attachment point: the same tensile force N will act throughout the PVC profile. Due to the symmetry of the problem, it is sufficient to consider only half of the profile. Results of the analytical solution for the described statements of the problem are shown below, computational schemes are shown in Figure 4.

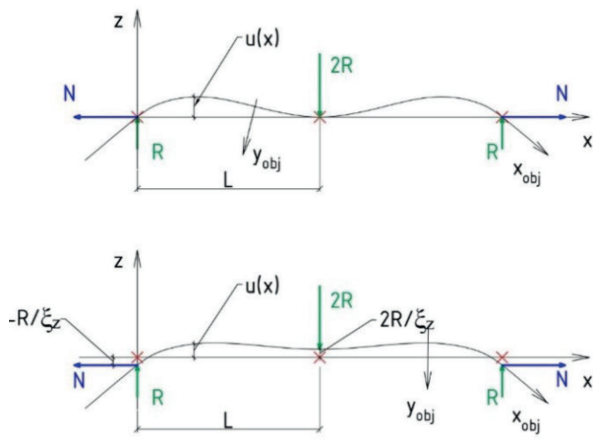

Figure 4. Calculation diagram (top – without taking into account compliance, bottom – taking into account compliance)

The equation for determining R:

1. Without consideration of compliance / without consideration of N:

$$R=-\frac{3K_{unc}EI}{2L}$$

2. Without consideration of compliance / with consideration of N:

$$R=-\frac{K_{unc}EI}{L}\cdot\frac{\left(1-e^{\omega L}\right)^{2}}{e^{2\omega L}+1-\frac{e^{2\omega L}-1}{\omega L}};\ \omega=\sqrt{\frac{N}{EI}}$$

3. With consideration of compliance / without consideration of N:

$$R=-\frac{K_{unc}EI}{L}\cdot\left(\frac{2}{3}+\frac{6EI}{L^{3}\xi_{z}}\right)^{-1}$$

4. With consideration of compliance / with consideration of N:

$$R=-\frac{K_{unc}EI}{L}\cdot\frac{\left(1-e^{\omega L}\right)^{2}}{\left(e^{2\omega L}+1\right)\left(1+\frac{3N}{\xi_{z}L}\right)-\frac{e^{2\omega L}-1}{\omega L}}$$

A comparative calculation on specific examples showed that the longitudinal forces have little effect, including on the values of transverse reaction forces (difference of about 3%). That is why here and in the following calculations they can be disregarded. At the same time, the joint compliance significantly reduces the value of transverse forces (by ≈30%), so it must be taken into account in the calculation.

2.2.3 Four attachment points

The calculation scheme for the considered case is shown in Figure 5. As justified above, the longitudinal forces will not be taken into account in determining the transverse reaction forces. The analytical solution for R is following:

$$R=-\frac{K_{unc}EI}{L_{1}}\cdot\frac{L_{1}+L_{2}}{\frac{4EI}{\xi_{z}L_{1}^{2}}+\frac{2}{3}L_{1}+L_{2}}$$

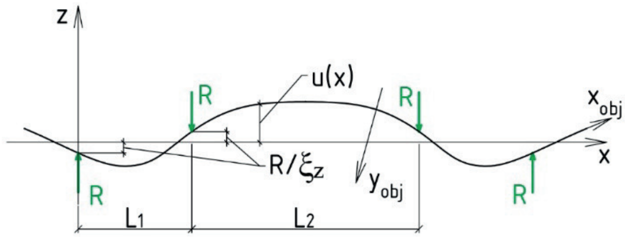

Figure 5. Calculation scheme

2.2.4 Joint compliance factor

In this article, two coefficients of the joint compliance "PVC profile – reinforcing core" were introduced in the calculations: longitudinal ξ_x and transverse ξ_z. The longitudinal compliance coefficient is caused by deformations of the connection node (local deformation of the profile wall, rotation of the screw under the action of the shear force). Calculations of the mechanical work of the profile together with the reinforcing core in the elastic formulation using a three-dimensional finite-element model allowed to estimate the value of ξ_x. It can be taken as 4.3…5·10^6 N/m. The question of the effect of PVC plastic properties on the value of ξ_x remains open. The transverse compliance coefficient is due in large part to the bending stiffness of the reinforcing core itself – with transverse loads, the core bends and the attachment points shift relative to the center line. The value of this displacement is directly proportional to the value of the shear force (which corresponds to the introduced definition of the value ξ_z). These considerations allow us to obtain the equations for ξ_z:

for three attachment points – $\xi_{z}=9\frac{E_{s}I_{s}}{L^{3}}$

for four attachment points – $\xi_{z}=\frac{E_{s}I_{s}}{L_{1}^{3}}\cdot\frac{12}{2+3\frac{L_{2}}{L_{1}}}$

With this in mind, the equations for R can be rewritten.

$$Rl_1 = -K_{unc}EI \Rightarrow R = -\frac{K_{unc}EI}{l_1}$$

2.2.5 More than 4 attachment points

With a larger number of attachment points, the outermost two (at the opposite ends of the profile) remain the most stressed, while there are almost no transverse forces at the central points. However, the redistribution of forces between the attachment points leads to a change in the shear forces arising at the extreme points with respect to those values determined by the formulas from the previous sections. The appearance of new attachment points violates the linear character of ξ_z, results in its increase (the core bends less at the same temperature moment), also the pairing of forces is violated: in the second attachment point from the edge, the shear force module will be slightly higher than in the first (by 8% tentatively). If this difference is neglected, then in first approximation we can assume that the pair of forces arising between the first attachment points fully compensates the temperature moment in the PVC profile section:

A more accurate determination of the transverse components of the reaction forces with a large number of attachment points is possible using a numerical solution. We can use the same physical model from which the formulas in section 2.2.4 were derived: two rods with different bending stiffness are connected at the attachment points by hinges, one of the rods tends to bend under the temperature load and bends the second rod by acting on it through the attachment points

3. RESULTS AND DISCUSSION

To check the correctness of the proposed methodology, a comparative calculation of the reinforced profile Veka system SL70 (see figure 6) on the temperature load was carried out. The same problem was solved analytically, as well as in the finite element modeling program COMSOL Multiphysics.

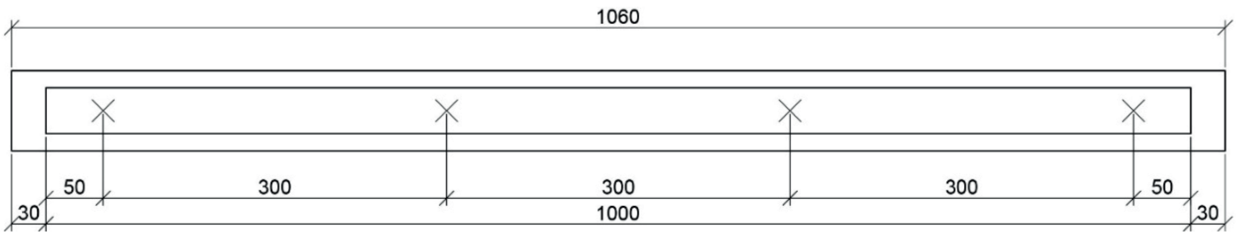

Figure 6. PVC profile with a length of 1,060 mm with a core of 1,000 mm, fastened with self-tapping screws in 4 places with the pitch of 300 mm

The calculation was performed for the following conditions: t_{ex} = -20°C; t_{in} = 20°C; $\alpha_в$ = 8.7 W/(m^2 °C); $\alpha_н$ = 23 W/(m^2 °C). For the profile in question its thermal resistance is known R_0 = 0.77 (m^2 °C)/W. The paper [24] described in detail how to use these data to calculate the temperature field in the cross section of the PVC profile (taking into account the reinforcing core) and to determine its parameters of free temperature deformation under the effect of this temperature field: the curvature (K_{unc}) and the longitudinal deformation coefficient (k_{ax}^{unc}). The results of the calculation using this method are shown in Figure 7. In this case, K_{unc} = -0,02567 1/m; $k_{ax}^{unc} = 0.998348$.

Let us write down all other necessary data for the calculation (see table 2).

Table 2. Calculation data

l_1	0.3 m	A_{PVC}	9.05 cm^2
l_2	0.3 m	E_{PVC}	$2.7\cdot10^9$ Pa
I_s	2.13 cm^4	α_{PVC}	$7\cdot10^{-5}$ K^{-1}
E_s	$2\cdot10^{11}$ Pa	ξ_x	$4.3\cdot10^6$ N/m
α_s	$1.2\cdot10^{-5}$ K^{-1}	T_m	-1.54 °C
I_{PVC}	58.62 cm^4	T_{ref}	20 °C

Solving the system of equations (*) and (**), we find: $N_1 = 1446$ N; $N_2 = 1855$ N; $N_3 = 1446$ N. Next, we determine the transverse force components:

$$R = -\frac{-0.02567\cdot2.7\cdot10^9\cdot58.62\cdot10^{-8}}{0.3}\cdot\frac{0.3+0.3}{\left(\frac{2}{3}\cdot0.3+0.3\right)\left(1+\frac{2.7\cdot58.62}{200\cdot2.13}\right)} = 118.5\text{ N}$$

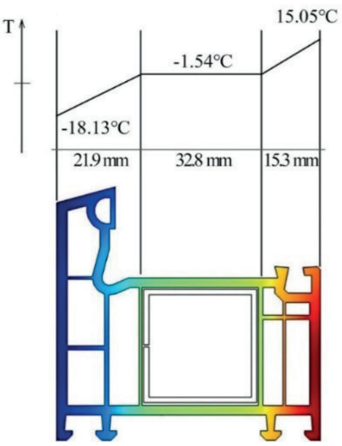

Figure 7. Temperature field

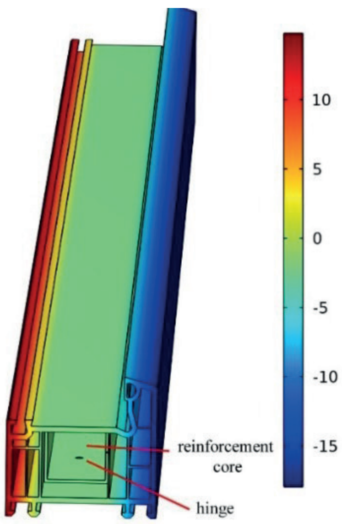

Figure 9. 3D model of the reinforced profile and the temperature field in it (legend in °C)

Thus, the forces acting on the reinforcing core from the PVC profile side will have the value shown in Figure 8.

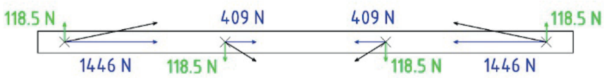

Figure 8. Forces acting on the core from the PVC profile side

In the COMSOL Multiphysics program (hereafter COMSOL), a similar problem was posed. The model created in COMSOL reflected the real three-dimensional geometry of the PVC profile and the core, all elements in it were considered to be perfectly elastic, at the points of self-tapping between the PVC profile and the core were given hinged connections. In the cross section of the profile elements, a temperature field similar to that shown in Figure 7 was set (see Figure 9).

To ensure the uniqueness of the solution, the boundary conditions of the "Rigid Connector" type were imposed on the end faces of the PVC profile in a flexible type of connection: on one end, connections were imposed for movements in all directions and for rotation around the longitudinal axis of the profile (x axis), on the other end, only for movements along the y and z axes (free rotations). Such boundary conditions do not create any obstacles for internal deformations of the profile, but provide its fixed position in space. The results of the simulation are shown in Figure 10. The reaction forces in the joints connecting the PVC profile and the core are shown in the table 3.

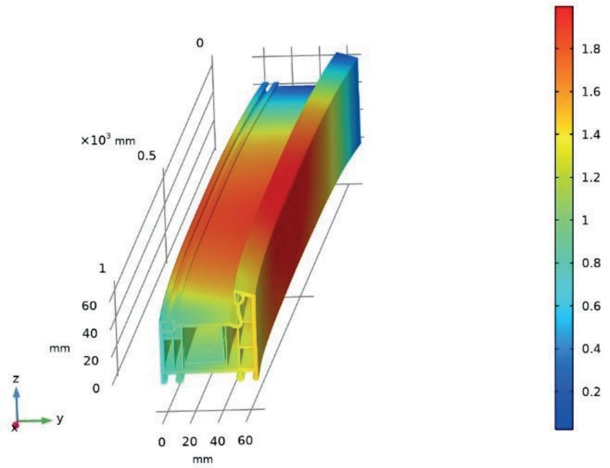

Figure 10. Deformations (legend in mm)

As can be seen, the results of the manual calculation according to the proposed method are in good agreement with the results of numerical modeling. The observed discrepancies are primarily due to the fact that the attachment points of the profile to the core (and consequently the application points of the reaction forces) are eccentric with respect to the neutral axes of the core and the profile itself, which causes: torsion (to which the metal core is more subject) and bending of the profiles not only around the z axis (axis position – see Figure 10), but also around the y axis. However, as part of the structure of the window, the PVC profile has less free deformation conditions. In this way the end edges of PVC profiles are rigidly connected to each other by welding, such a connection prevents the torsion of the profiles and their bending around the second axis (thereby bringing the real picture of the stress-strain state of the profile even closer to the model that was developed in this article). These prerequisites will make it possible to determine the forces occurring in the corner joints of PVC windows, which will be a topic for further work by the authors.

Table 3. Comparison of calculation results

No. of joint	Based on simulation results		Based on manual calculation results		Divergence, %	
	Longitudinal component	Transverse component	Longitudinal component	Transverse component	Longitudinal component	Transverse component
1	1325 H	110.3 H	1446 H	118.5 H	-9.1	-7.4
2	447 H	-110.3 H	409 H	-118.5 H	8.5	-7.4
3	-447 H	-110.3 H	-409 H	-118.5 H	8.5	-7.4
4	-1325 H	-110.3 H	-1446 H	118.5 H	-9.1	-7.4

4. CONCLUSION

In this work, a method of analytical calculation of the temperature deformation of a PVC profile reinforced with a metal core was proposed, thus:
1. The nature of the forces occurring at the attachment points of the reinforcing core to the PVC profile was described. The greatest forces occur in the extreme fasteners that fix the PVC profile to the reinforcing core. The compliance of these joints has a decisive influence on the deformation of PVC profiles under the action of temperature loads.
2. A mathematical model was developed to calculate the longitudinal components of the forces in the attachment points due to different values of temperature shrinkage of PVC profile and reinforcing core;
3. A mathematical model was developed to calculate the longitudinal components of the forces in the attachment points caused by the thermal bending of the PVC profile;
4. In order to increase the calculation accuracy with a large number of attachment points (for long profiles), a physical model of the joint mechanical operation of PVC profile and core

was proposed, this model is planned to be implemented in the numerical calculation program;
5. A comparative calculation of the bending of a reinforced PVC profile with a length of 1 m using the proposed methodology, as well as with the full three-dimensional finite-element modeling in the program COMSOL Multiphysics was carried out. Comparison of the calculation results showed convergence with an error of less than 10%.

The theoretical conclusions proposed in this article are part of a more extensive, currently under development methodology for calculating the mechanical operation of modern window structures with regard to temperature loads. This methodology will allow engineers to make effective decisions early in the design process and greatly reduce the amount of expensive and time-consuming laboratory testing.

In what follows, the authors propose to consider the following issues:
1. Influence of plastic properties of PVC on the value of the coefficient of transverse compliance of joints "PVC profile – reinforcing core" ξ_z;
2. Oblique bending of PVC profiles (this problem is especially acute for PVC profiles with a marked asymmetry of the cross-section);
3. Static operation of the nodes connecting the profile elements of the window with each other;
4. Influence of rigidity of translucent filling (insulating glass unit) and bracing elements of fittings on deformations of profile window elements.

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