Increasing Energy Efficiency of the Translucent Enclosure Walls of a Building

Josifas Parasonis, Andrius Keizikas*
Vilnius Gediminas Technical University, Sauletekio av. 11, LT-10223 Vilnius, Lithuania

Abstract

Until the 21st century, in the countries of cold climate, windows have been considered to be the elements of the buildings, through which large quantities of heat leak in the heating season. Nowadays modern technologies allow engineers to improve thermodynamic characteristics of these external enclosures, so that in some cases, even a favorable thermal balance can be obtained. However, better results can still be achieved. The paper presents the results of the research into energy balance of enclosure walls depending on geometric characteristics and glazed areas of a building. In this context, the possibility of using a dynamic window protection system is discussed and its influence on the energy balance is determined. The results obtained show that the influence is considerable.

Keywords: Energy efficiency, dynamic window protection, building compactness.

Nomenclature

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>building envelope area ($m^2$)</td>
</tr>
<tr>
<td>b</td>
<td>time of application of a measure per day (h)</td>
</tr>
<tr>
<td>g</td>
<td>solar heat gain coefficient</td>
</tr>
<tr>
<td>$l_s$</td>
<td>solar flux density (W/m$^2$)</td>
</tr>
<tr>
<td>R</td>
<td>thermal resistance ($m^2\cdot K)/W$</td>
</tr>
<tr>
<td>q</td>
<td>annual energy losses per an enclosure area (kWh/ m$^2\cdot A$)</td>
</tr>
<tr>
<td>$q_s$</td>
<td>annual energy gains per an enclosure area (kWh/ m$^2\cdot A$)</td>
</tr>
<tr>
<td>Q</td>
<td>annual energy balance per house area (kWh/ m$^2\cdot A$)</td>
</tr>
<tr>
<td>S</td>
<td>area of a building ($m^2$)</td>
</tr>
<tr>
<td>U</td>
<td>heat transfer coefficient (W/(m$^2\cdot K$))</td>
</tr>
</tbody>
</table>

Greek symbols

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\theta$</td>
<td>temperature ($^\circ C$)</td>
</tr>
</tbody>
</table>

Subscripts

<table>
<thead>
<tr>
<th>Subscript</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>m</td>
<td>number of a month</td>
</tr>
<tr>
<td>i</td>
<td>internal</td>
</tr>
<tr>
<td>e</td>
<td>external</td>
</tr>
<tr>
<td>se</td>
<td>external layer</td>
</tr>
<tr>
<td>wd</td>
<td>window</td>
</tr>
</tbody>
</table>

* Corresponding author. Tel.: +370 5 274 5249.
E-mail address: andrius.keizikas@vgtu.lt
1. Introduction


To achieve this, the investigations aimed at optimizing the volume and shape of a building, as well as building materials, structural units’ design, heating and ventilation, and the use of renewable energy sources, are made and the related problems are studied [4–6]. The present research may be referred to studies, associated with heat conservation in buildings, whose aim is to minimize energy losses of a building through external enclosures. The aim of the present work is the search for means and methods of minimizing energy losses through windows.

Having evaluated energy efficiency of Lithuanian apartment buildings constructed in various periods of time, the authors have found that windows are the leader among the enclosures with respect to heat losses [7]. The latter would remain the highest even if the enclosures with thermal resistance meeting the requirements of nearly zero-energy building or a “LONGLIFE” energy efficient apartment house [8–11] were used. It is true that modern windows can partially compensate for the leaked energy by the influx of radiant solar energy (i.e. gains) [12], which was confirmed by the authors of this paper. In the climate conditions of Lithuania, they can demonstrate the same or even more favorable heat balance in the cold season than that of the external walls, however, only in the South direction. Thus, it can be stated that the size and proportions of a building largely determine the area of enclosures, as well as energy losses and gains (depending on the amount of windows in the enclosure) [13, 14]. Therefore, in the present research, the efforts were made to evaluate the effect of minimizing energy losses through translucent enclosures, taking into account the size and proportions of a building, as well as the number of windows in it.

2. The problem and the aim of the research

Searching for the ways of increasing solar energy absorption, the researchers offered various solutions for building façade modification. They include: a) double glazed facades, winter gardens and other closed zones of a building, reducing energy losses due to leakage [15, 16]; b) “Trombe” walls and other indirect heat transfer systems (roof-pond, etc.) [17]; c) solar collectors and other active energy absorbing systems [18]. However, most of the mentioned authors, as well as [19, 20], emphasize that energy is mainly obtained as the solar rays penetrating through windows, while each additional intermediate area or accumulation system experiences some additional losses, reducing the total amount of the absorbed energy.

Taking into account the considered problems, energy performance of windows in the wintertime should be particularly efficient. When the sun shines, they should admit the maximum amount of the radiant energy (gains) and, particularly, in the dark time, to lose a minimum amount of heat by transfer. This is feasible, if a building has the so-called “dynamic” characteristics, allowing it to adapt to ever-changing external environment. Lechner [5] refers the ability of windows to protect the premises from the excessive solar radiation in summer, when the external “shadow” elements are used, to dynamic characteristics. We suggest that the external dynamic elements should be used for windows in the cold weather. They would protect the windows on the principle of shutters, which can be shut in the dark period of a day and open in the daylight.

The present research is aiming to assess the effectiveness of additional protection by decreasing energy losses through windows, as well as their use, depending on the building size and proportions. For this purpose, the comparative analysis principles were used.

The effect of analogical solutions aimed at increasing the effectiveness of windows was also evaluated by Garber-Slaght and Craven [24]. The authors report that a window covered for 12 hours in the climatic conditions of Alaska, can show thermal energy saving by tens percent higher than others, depending on the window itself and the additional thermal insulation characteristics, imparted to it. These authors note that the effect (in percent) is higher for worse windows, though their total values for energy saving are lower than those that the best windows without any additional protection available on the market can offer. The authors also state that the dynamic protection elements fixed within the premises are easier to control, though causing condensation, while external shutters are more difficult to control from the inside, but do not cause any condensation problems.

There is a great number of patented engineering solutions in the world, concerning the possibilities of using the dynamic window protection systems similar to those discussed above. They may be fixed in the premises, outside or the inside the window frame, and have various thickness, optical and thermodynamic characteristics, etc. [22–25]. For the purposes of the
such buildings. Different dimensions and proportions, and energy balance of external enclosures is determined for the heated unit area of enclosure. At the second stage, the calculated values of losses per unit area are assigned to the surfaces of buildings (walls, floors, roof, and windows with dynamic protective layers) of an imaginary building are determined per unit area of enclosures per unit area is obtained for one heating season.

A description of the method used

The calculations are performed in the research in two stages. At the first stage, energy losses through external enclosures (walls, floors, roof, and windows with dynamic protective layers) of an imaginary building are determined per unit area of enclosure. At the second stage, the calculated values of losses per unit area are assigned to the surfaces of buildings of different dimensions and proportions, and energy balance of external enclosures is determined for the heated unit area of such buildings.

Following the recommendations of the Lithuanian standard STR2.01.09: 2012, monthly energy losses per unit area of the external enclosure \( q_m \) and the gains \( q_{g,m} \) are expressed by the Eqs (1) and (2):

\[
q_m = 0.001 \cdot t_m \cdot b \cdot (\theta_i - \theta_{e,m}) \cdot U
\]

\[
q_{g,m} = 0.001 \cdot t_m \cdot b \cdot (l_{sol,m} \cdot g_{wd} - R_{se} \cdot h_{se,r} \cdot \Delta \theta_{er} \cdot U_{wd})
\]

where \( t_m \) is the number of days in a month, \( b \) is the number of hours in a day, when the enclosure’s element maintains its thermal insulation characteristics; \( \theta_i \) is the inside temperature equal to 20 °C; \( \theta_{e,m} \) is the average monthly temperature; \( U \) is heat transfer coefficient of the enclosure’s element, W/(m²K); \( l_{sol,m} \) is the average monthly solar flux density; \( g_{wd} \) is solar heat gain coefficient of a window; \( R_{se} \) is thermal resistance of the enclosure surface, equal to 0.04 (m²K)/W; \( h_{se,r} \) is the coefficient of radiant thermal energy transfer, equal to 4.5 W/(m²K); \( \Delta \theta_{er} \) is the average temperature difference between outside air and the sky shell, assumed to be 11 °C; \( U_{wd} \) is the declared heat transfer coefficient of a window W/(m²K).

A sample of dimensions and proportions of buildings, to whose external enclosures the values of heat losses and gains, calculated by the Eq. (1) and (2) are assigned, is taken from the work [15]. In this research, the values of the evaluated buildings (the internal areas) vary within the limits of 50–5000 m² (with the floor height 3.2 m), while their rectangular proportions \((x_1; x_2; x_3, \text{ representing length, depth and height})\) vary from 1:1:1 to 1:1:4 and 4:1:1 and also 2:1:(x); 4:1:(x); (z):1:2 and (z):1:4, where z is the shortest side value, satisfying the relationship between other sides.

Given the building area \( S \), the area of the external enclosures \( A \) and the respective heat balance of losses \( q_m \) and gains \( q_{g,m} \) are determined, based on the specified proportions’ limits and the amount of windows in facades. By dividing energy balance of the building external enclosures by the internal (heated) area \( S \), the energy balance \( Q \) of the building external enclosures per unit area is obtained for one heating season.

The above values, determined for buildings of various areas, equipped or not equipped with the dynamic protection elements, are compared with each other and, based on this comparison, the conclusions are made for the research performed.
4. The calculation data and the results obtained

The comparative calculations of energy balance of buildings with respect of energy leakage through their external enclosures were made during the heating season from October till April. Thermodynamic characteristics of some enclosure elements (e.g. walls, roof, windows and the first level floors) were taken from [9]. The heat transfer coefficient of the dynamic window protection system, mainly made of VIP plates, is assumed to be equal to 0.006 W/m²K (i.e. the average value of the first 25 years of its service). The window protection system is assumed to be leak-proof from infiltration losses during the calculation. Energy gains from non-transparent enclosures they are not considered because it is not relevant for the final result. The data on thermodynamic enclosure characteristics, as well as the time of using the dynamic window protection per day, are given in Table 1.

Table 1. The values of thermodynamic characteristics of external enclosures and the time of their application per 24 hours

<table>
<thead>
<tr>
<th>Enclosure element</th>
<th>Wall</th>
<th>1st level floors</th>
<th>Roof</th>
<th>Windows*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Without protection</td>
</tr>
<tr>
<td>U-value, W/(m²K)</td>
<td>0.12</td>
<td>0.12</td>
<td>0.12</td>
<td>0.73</td>
</tr>
<tr>
<td>Applied per day, h</td>
<td>24</td>
<td>24</td>
<td>24</td>
<td>24</td>
</tr>
</tbody>
</table>

*Solar heat gain coefficient g_{wd} = 0.49

Since solar energy gain of a building depends on its orientation, it is assumed in this work that the volume variants of all buildings are oriented by their largest facades to the South, where the largest gains are expected.

The obtained energy balance values per unit area of the premises, which refer to external enclosures, as well as their dependence on the building dimensions and proportions, are graphically shown below. The window area on all facades is assumed to be the same. The graphs of buildings, provided and not provided with the dynamic protection elements, are given in pairs. The first ones present only the losses through external enclosures (Fig. 1), when 50 percent of the façade area is glazed. The second ones (Fig. 2) show energy balance (including both energy losses and gains), referring to the external enclosures with similar glazed areas. Others also show energy balance, though the glazed area is either decreased to 20 percent (Fig. 3) or increased to 70% of the façade area (Fig. 4).

![Fig. 1](image1.png)

Fig. 1. Energy losses of buildings of various dimensions and proportions, per their external enclosures, which have a) windows without any protection elements; b) windows with dynamic protection elements. The glazed façade area is 50%
Fig. 2. Energy balances of buildings of various dimensions and proportions, referring to their external enclosures, which have a) windows without any protection elements; b) windows with dynamic protection elements. The glazed façade area is 50%.

Fig. 3. Energy balances of buildings of various dimensions and proportions, referring to their external enclosures, which have a) windows without any protection elements; b) windows with dynamic protection elements. The glazed façade area is 20%.

Fig. 4. Energy balances of buildings of various dimensions and proportions, referring to their external enclosures, which have a) windows without any dynamic protection elements; b) windows with dynamic protection elements. The glazed façade area is 70%.
All graphs show that the additional protection of windows helps to decrease heat losses through external enclosures. Depending on the glazed area, the dynamic window protection elements can increase energy efficiency of enclosures by tens of percent.

When the first graphs, presenting only losses, are compared, they show buildings without window protection, having the area of about 200 m$^2$ and demonstrating 75–105 kWh of annual heat losses per unit area. At the same time, the protection of windows in a building may decrease the losses to 50–65 kWh/m$^2$A (i.e. the average effect is 30 kWh/m$^2$A). For the buildings with the area 1000 m$^2$ these values are respectively 43–60 and 28–38 kWh/m$^2$A (the average effect is 11 kWh/m$^2$A).

Adding the values of solar gains through windows to the values of losses given in Fig. 1, we get two graphs shown in Fig. 2. It can be seen that the dynamic protection elements provide a building with a possibility to lose less heat through the enclosure walls, than can be obtained from the environment. Under these conditions, window performance in the cold season becomes more effective than wall performance. Therefore, it should be useful to see how the number of the windows on the façade affects the total energy balance per unit area of the building, referring to the enclosure walls.

In Fig. 3, where it is shown, that the amount of the translucent enclosures is decreased to 20%, the effect produced by shutters is not sufficient to make energy balance associated with enclosures, positive. When the area is about 200 m$^2$, the variant without shutters demonstrates the losses about 21 kWh/m$^2$A, while the variant with the shutters used shows the losses of about 8 kWh/m$^2$A (the average effect is 13 kWh/m$^2$A). When the building area reaches 1000 m$^2$, the respective values are (–12) and (–4) kWh/m$^2$A, and when the building area reaches 5000 m$^2$, the average values of (–7) and (–3) kWh/m$^2$A are obtained. It follows that the effect of using the additional window protection decreases for large buildings with a relatively small glazed area.

In Fig. 4, the maximum energy balance of the enclosure walls is shown, as the maximum potential of windows is used (it would be hardly possible to make a façade with more than 70% of translucent enclosures because of the structural elements occupying the rest of the façade: floor slabs, lintels, suspended ceilings, etc.). In this case, buildings with dynamic window protection elements demonstrate the results largely exceeding the average values (which allows us to assume that the active heating systems would be minimally used in the cold season). The effect of shutters application is also the highest in this case. For buildings of 200 m$^2$ floor area, it varies in the values exceeding 40 kWh/m$^2$A. When the building area reaches 1000 m$^2$, the results higher by about 25 kWh/m$^2$A are obtained, while for the area of 5000 m$^2$, it is about 12 kWh/m$^2$A. Similar to the above-mentioned figures, the shutters effect is larger for smaller buildings than for large buildings.

Comparing the graphs, one can see that the number of windows on the façade determines both the variation of energy balance (from negative for a minimum glazed area to positive for a maximum glazed area) and the influence of the building proportions on the estimated energy balance. The calculation results presented in Fig. 2, show that building proportions determine only about 3 kWh/m$^2$A of the losses experienced by buildings without shutters and 8 kWh/m$^2$A by buildings with shutters, while, in Fig. 4, building proportions determine the spread of values up to 15 and 40 kWh/m$^2$A, respectively (the balance values corresponding to the buildings with the area smaller than 100 m$^2$ are rejected because they reflect the irrational dimensions of buildings).

Summarizing the effect of the dynamic protection elements on energy balance associated with the performance of external enclosures and taking into account the variation of building dimensions and proportions, it may be stated that the highest effect of these elements can be achieved, when they are used in the smaller area buildings. However, when the glazed window area is too small (implying that the effect of shutters is small), the energy balance, depending on the performance of the enclosure walls, is improving with the increase of building dimensions.

The calculated effect of an additional window protection could be higher if its dynamic elements were applied not based on the average temperature during 12 hours a day, but took into account different day and night temperature, the varying length of these time periods and the environmental effect, as well as the type, function and orientation of a building. Thus, the bathroom window oriented to the North can be uncovered only at the time of using bathroom. We think that the data presented in this work make a sound base for a more detailed study.

5. Conclusions

An additional dynamic window protection system is an effective means of decreasing heat losses in buildings through translucent enclosure walls, which can help them to approach nearly zero-energy building standard.

The dynamic window protection elements, additionally protecting windows from the night frost and allowing them to gain solar energy in the daytime, provides a possibility to translucent enclosures to achieve more favourable thermal balance than that of the external walls.

The effect of using the additional window protection elements on decreasing heat losses through enclosures is inversely proportional to a size of a building.
The amount of windows on the façade determines both the total energy balance of enclosure and the effect of building proportions on energy balance. When windows occupy 70 percent of façade area, the proportions determine the spread of the results several times higher than that recorded for windows, occupying 20% of the façade area.

The obtained results show that the solutions of the dynamic window protection elements deserve attention both from the perspectives of detailing the research in this area and searching for the ways of increasing its effectiveness.

References