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THE INFLUENCE OF ENVELOPING ON ENERGETIC AND ECOLOGICAL EFFICIENCY OF PASSIVE HOUSES

R. MOLDOVAN[1] **G. DRAGOŞ**[1]

Abstract: *Within the European energetic and ecological context of reducing energy consumption and polluting emissions, a major role will be played by designing energetically efficient buildings, such as passive houses. In view of improving energetic and ecological performances of these buildings, the emphasis will primarily be laid on improvement at the level of envelope elements aiming at both diminishing energy losses – limiting heat transfer coefficients in conformity with passive standards – by using some highly efficient insulating materials and reducing the negative impact on surroundings by using ecological materials.*

Key words: *energy efficiency, passive house, building enveloping, global heat transfer coefficient.*

1. Introduction

Within the present context of increasing energetic needs implying an increase of toxic emissions, the energetic policies of EU will aim at providing a long lasting, competitive and secure development of energy supply. In this respect, the energetic and climatic objectives of the EU, contained in “the Europe 2020 strategy” will pursue the following targets for 2020 [6]:

- improving energetic efficiency by 20%;
- diminishing greenhouse effect emissions by at least 20% as compared with 1990 level;
- increase in the proportion of renewable sorts within the total energy consumption to 20%.

Taking into account that the construction area registers the highest consumptions of energy and greenhouse effect emissions, emphasis will be placed on promoting energetic efficiency in buildings by [5]:

- stimulating restoration processes with the existent building;
- improving energetic performances at the enveloping elements level;
- improving energetic performances at the level of energy supply.

The energetically efficient buildings, part of which are the passive houses, too, aim at reducing energy consumption, diminishing greenhouse effect emissions and improving the degree of using renewable sources of energy.

To get to these objectives along with providing the quality requirements of internal comfort, an essential role will be played by the envelope of the building.

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[1] Faculty of Building Services, Technical University of Cluj-Napoca.

2. Measures to improve energetic performances of enveloping

One of the basic principles in building passive houses consists in applying passive designing strategies [1], [3]:

- compact forms, in view of minimizing building surfaces as compared with its volume in order to reduce heat losses to the exterior;
- a proper orientation of the building in view of maximizing solar heat contribution in cold seasons and minimizing it in hot seasons, along with providing some schemes of solar control;
- a good thermal insulation capable to reduce heat losses to the exterior in cold seasons by using some innovative solutions and some performant materials from insulating property point of view;
- a proper insulation against penetration of cold air and diminishing heat losses to the exterior.

The energy losses through envelope elements are given by the global heat transfer coefficients (U) whose values, in accordance with the climatic zone should lie between limits [8]:

- 0.15 W/m^{2}K for opaque components of the envelope;
- 0.8 W/m^{2}K for vitrified components.

2.1. Opaque components

Opaque components of envelope (external walls, slabs, floor slabs, roofs, terrace slabs) offer various constructive possibilities that can be made of massive masonry walls and insulating layers, prefab elements, walls with high thermal inertia, dynamic insulation systems or dynamically adaptive systems.

The main method of improving energetic performances of opaque elements of envelope consists in diminishing global heat transfer coefficient. This represents the heat flux transmitted to 1 m^2 of wall surface, at a temperature difference of one degree and is calculated as follows [2]:

$$U = \frac{1}{\frac{1}{h_i} + \sum_{i=1}^{NS} \frac{\delta_i}{\lambda_i} + \frac{1}{h_e}} \tag{1}$$

where:

h_i is surface coefficient of heat transfer to interior, [W/m^{2}K];

$\sum_{i=1}^{NS} \frac{\delta_i}{\lambda_i}$ – amount of conductive thermal resistance for all NS-layer wall, [m^{2}K/W];

δ_i – thickness of each layer of the wall, [m];

λ_i – thermal conductivity coefficient of each layer of wall, [W/mK]

h_e – surface coefficient of heat transfer to exterior, [W/ m^{2}K].

In order to fulfil the passive house standards, the opaque elements of the envelope should provide a global heat transfer coefficient U≤0.15 W/m^{2}K. In this respect, one recommends the use of some thermo insulating materials of thermal conductivity (λ) as low as possible and with a poor impact upon environment (kg CO_2 equivalent) such as:

- expanded polystyrene (EPS):
  λ =0.033-0.04 W/mK,
  7.36 kg CO_2 equivalent;
- extruded polystyrene (XPS):
  λ =0.032-0.038 W/mK,
  14.26 kg CO_2 equivalent;
- styropor/neopor:
  λ =0.035-0.031 W/mK,
  7.36 kg CO_2 equivalent;
- rockwool:
  λ =0.034-0.04 W/mK,
  1.04 kg CO_2 equivalent;
- transparent insulation - aerogel:
  λ =0.013-0.014 W/mK,
  4.2 kg CO_2 equivalent.

2.2. Windows

The vitreous component of building envelope – the windows – should play a double role: to reduce energy losses and improve sun contributions.

To reduce losses, measures of improving energetic performances of windows are to be taken by reducing the global heat transfer coefficients U_w.

The calculation of coefficient U_w is carried out as follows [9]:

$$U_w = \frac{A_g \cdot U_g + A_f \cdot U_f + l_g \cdot \Psi_g \left(+ l_{inst} \cdot \Psi_{inst}\right)}{A_g + A_f} \tag{2}$$

where:
U_w is global heat transfer coefficient of the window, [W/m^{2}K];
A_g – area of the glazing, [m^2];
U_g – heat transfer coefficient of the glazing, [W/m^{2}K];
A_f – area of the frame, [m^2];
U_f – heat transfer coefficient of the frame, [W/m^{2}K];
l_g – glass edge length, [m];
Ψ_g – linear heat transfer coefficient (determined by the spacer profile), [W/mK];
l_{inst} – frame edge length, [m];
Ψ_{inst} – linear heat transfer coefficient (due to installation), [W/mK].

In view of limiting coefficient U_w in accordance with requirements imposed to passive buildings - $U_w \leq 0.8$ W/m^{2}K – one aims at reducing heat transfer coefficients at glass, frame and spacing device level.

The reduction of heat transfer coefficient for glass (U_g) may be achieved through the following methods:

- increasing the number of glasses and the spaces in between and replacing the air between glass panes with noble gases - argon (Ar), krypton (Kr);
- use of low emissivity glass.

In order to secure a positive energetic balance in the cold season (the solar contribution given by the sun factor g should be greater than the energy losses given by coefficient U_g), the windows of the passive buildings should meet the condition [1]:

$$U_g - 1.6\, W/(m^2K) \cdot g \leq 0 \tag{3}$$

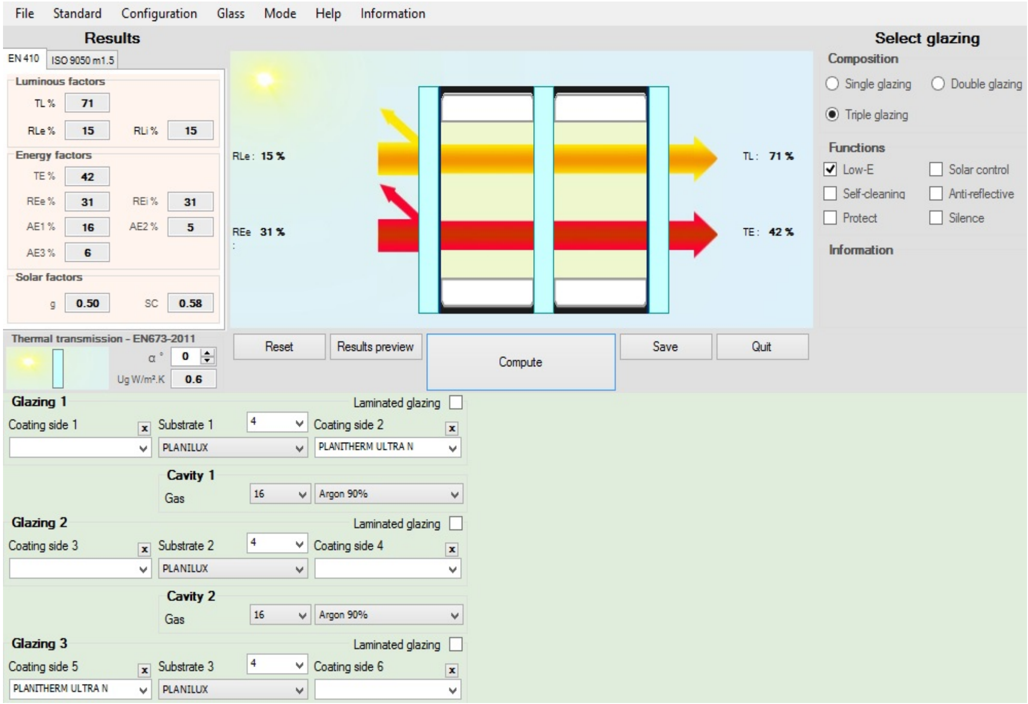
a fact leading to the following limitations: $U_g \leq 0.8$W/m^{2}K and $g \geq 0.5$.

Consequently, the windows made of triple glass panes with two low emissivity layers and the spaces between window panes filled with noble gases are proper for building passive houses, an example in this respect is represented in Figure 1.

For diminishing heat transfer coefficient for frames (U_f) some very good insulating materials are recommended, and for reducing linear heat transfer coefficient (Ψ_g), given by frame-spacer profile ensemble the use of warm edge spacers are recommended instead of aluminium spacers.

3. Case study. Implementing the model and simulation results

Considering that a primary role in improving energetic and ecological performances of passive houses is played by envelope, a case study was carried out, based on dynamic simulations starting from a model house situated in the III climatic zone (Cluj-Napoca).



Results

Luminous factors: TL % 71; RLe % 15; RLi % 15

Energy factors: TE % 42; REe % 31; REi % 31; AE1 % 16; AE2 % 5; AE3 % 6

Solar factors: g 0.50; SC 0.58

RLe : 15 %; TL : 71 %; REe 31 %; TE : 42 %

Thermal transmission - EN673-2011: α ° 0; Ug W/m².K 0.6

Select glazing

Composition: ○ Single glazing ○ Double glazing ● Triple glazing

Functions: ☑ Low-E ☐ Solar control ☐ Self-cleaning ☐ Anti-reflective ☐ Protect ☐ Silence

Information

Glazing 1 Laminated glazing ☐
Coating side 1:
Substrate 1: 4, PLANILUX
Coating side 2: PLANITHERM ULTRA N

Cavity 1 Gas: 16, Argon 90%

Glazing 2 Laminated glazing ☐
Coating side 3:
Substrate 2: 4, PLANILUX
Coating side 4:

Cavity 2 Gas: 16, Argon 90%

Glazing 3 Laminated glazing ☐
Coating side 5: PLANITHERM ULTRA N
Substrate 3: 4, PLANILUX
Coating side 6:

Fig. 1. *Triple glazing with 2 low emissivity and argon filled space [4]*

The study pursues the energetic and ecological analysis of various solutions of making the envelope, in correlation with the climatic zone, orientation, building materials, proportion of glass surfaces, degree of shaded zones, so meeting the standards of passive houses.

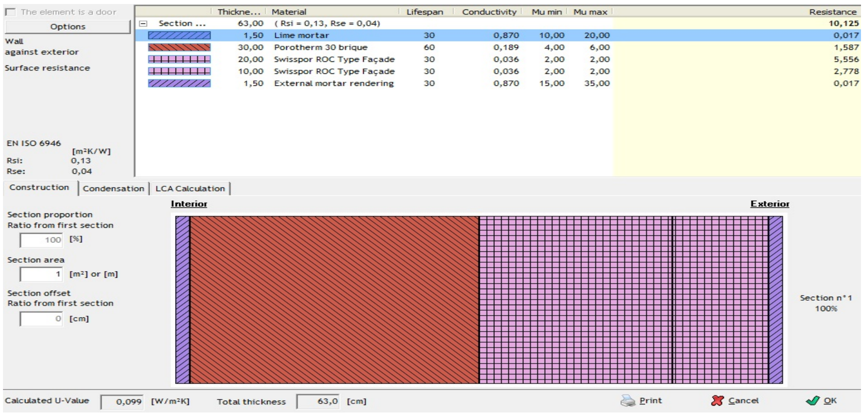
The simulation was achieved with Lesosai soft, in conformity with the European CEN EN 13790 (hourly calculation), aiming at both the determination of thermal transfer coefficient and the impact of envelope upon the environment.

Starting from one of the major characteristic of passive houses, namely providing a high standard of thermal insulation – a first analysis aimed at the influence of various solutions of making envelopes taking into account the following material and technologies for the opaque elements of envelope:

- case 1a: brick masonry walls and rockwool thermal insulation at wall, roof, floor slab level 30/40/40 cm;
- case 1b: brick massive walls and polystyrene (EPS, XPS) 30/40/40 cm thermal insulation;
- case 1c: prefab elements – neopor concrete filled casings 29/30/30 cm.

Determining heat transfer coefficients U was carried out on the basis of Lesosai program using the materials Library. A detail concerning an external brick wall structure and rockwool insulation (case 1a) is shown in Figure 2.

For each of the three cases both at external walls level and at floor slab and roof level, heat transfer coefficients U below limits imposed to passive houses have been obtained, as can be seen in Figure 3.



☐ The element is a door

Options

Wall
against exterior

Surface resistance

	Thickne...	Material	Lifespan	Conductivity	Mu min	Mu max	Resistance
⊟ Section ...	63,00	(Rsi = 0,13, Rse = 0,04)					10,125
▨	1,50	Lime mortar	30	0,870	10,00	20,00	0,017
▨	30,00	Porotherm 30 brique	60	0,189	4,00	6,00	1,587
▦	20,00	Swisspor ROC Type Façade	30	0,036	2,00	2,00	5,556
▦	10,00	Swisspor ROC Type Façade	30	0,036	2,00	2,00	2,778
▨	1,50	External mortar rendering	30	0,870	15,00	35,00	0,017

EN ISO 6946
[m²K/W]
Rsi: 0,13
Rse: 0,04

Construction | Condensation | LCA Calculation

Section proportion
Ratio from first section
100 [%]

Section area
1 [m²] or [m]

Section offset
Ratio from first section
0 [cm]

Calculated U-Value 0,099 [W/m²K] Total thickness 63,0 [cm]

Fig. 2. *Detail of the structure of an outside wall (case 1a) [7]*

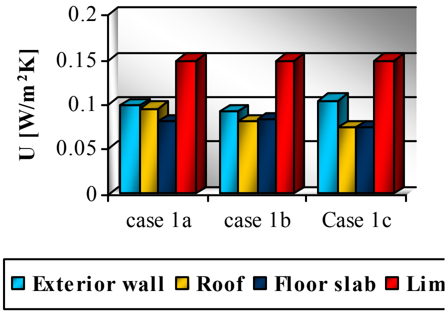


Fig. 3. *Values of heat transfer coefficient*

Further on, heat transfer coefficients U were, in conformity with climatic zone III limited, so that the model house should meet the condition of passive houses (with annual energy consumption for heating/ cooling ≤15kWh/m^{2}year).

In conformity with the results obtained for climatic zone III the limitation of heat transfer coefficients U at wall/roof/floor slab levels have been recommended to 0.11/0.10/0.10 W/m^{2}K.

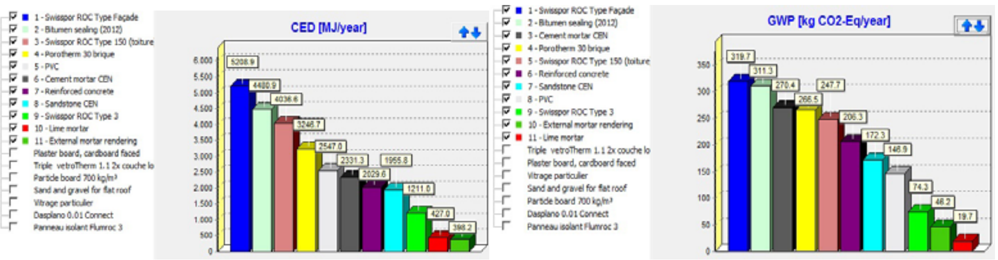
Comparing the variants studied one observes that the best coefficients at the external walls level were obtained in case 1b, as a result of low conductivity of EPS (λ=0.033 W/mK), and at roof and floor slab level, in case 1c, as a result of using neopor (λ=0.033 W/mK).

The impact of passive houses on environment is given by two indicators:

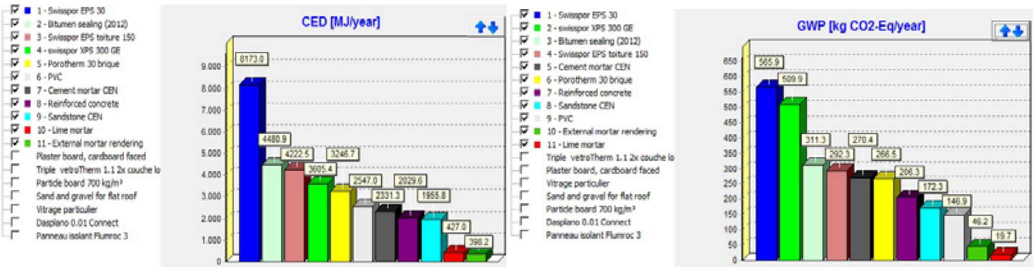
- global warming potential (GWP);
- cumulative energy demand (CED).

Figure 4 shows the variation of the two impact indicators for each case analyzed, setting into evidence materials with highest energetic consumptions and green house effect emissions.

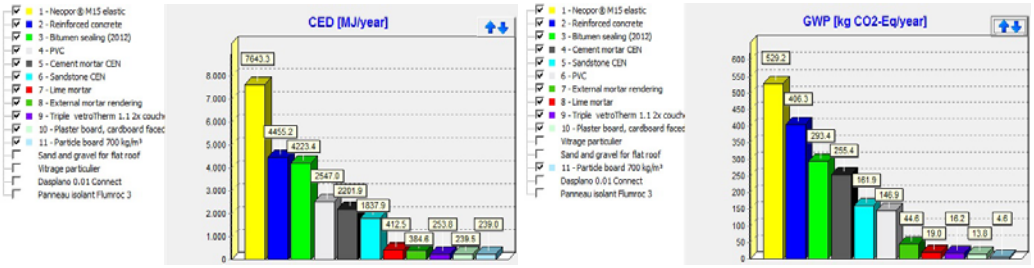
For each building material one has considered their production, replacing and elimination, the variation of impact indicators being shown in Figure 5.



Case 1a



Case 1b



Case 1c

Fig. 4. *The influence of building materials on CED and GWP indicators [7]*

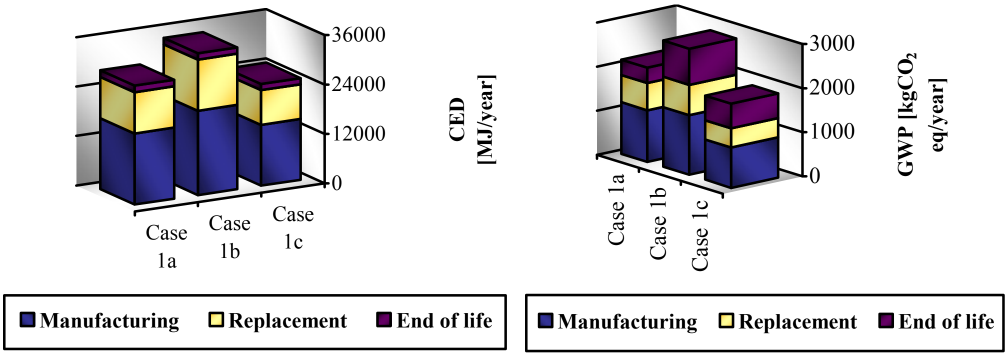


Fig. 5. *Variation of CED and GWP for building materials*

Making a comparison between the three cases one notices the followings:

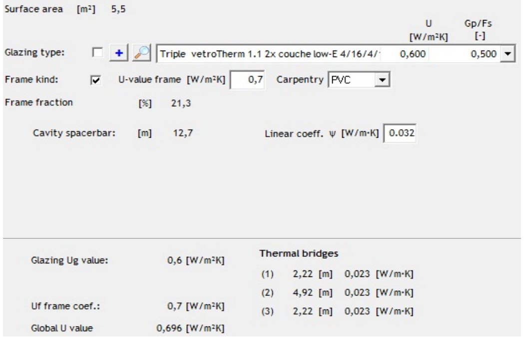
- as a result of large insulating thicknesses, the highest energetic consumptions come with EPS insulation (8173 MJ/year), followed by neopor (7643 MJ/year) and rockwool (5208.9 MJ/year);
- as GWP is concerned, the highest emissions come with EPS insulation (565.9 kg CO_2-eq/year), neopor (529.2 kg CO_2-eq/year), XPS (509.9 kg CO_2-eq/year) and concrete (406.3 kg CO_2-eq/year – as a result of high quantities used with casings) while the impact of rockwool is 319.7 kg CO_2-eq/year;
- the highest energy consumptions for manufacturing and replacing materials were recorded with EPS and XPS insulation, their elimination in case of using rockwool, and the lowest values were obtained with neopor casings (1904.73 MJ/year);
- the largest polluting emissions were obtained in the case of EPS and XPS insulation (2856.96 kg CO_2-eq/year),

and the lowest emissions for the manufacturing, replacement of materials in case of neopor casings and their elimination in case of rockwool insulation.

Another remarkable role in providing a high standard of thermal insulation comes with windows. So, starting from the initial parameters of the house, a second analysis has in view various solutions of making windows considering the following cases of windows with three glass panes with 2 low emissivity layers and warm edge spacers:

- case 2a: PVC frames with Ar interspaces;
- case 2b: wooden frames with Ar interspaces;
- case 2c: PVC frames with Kr interspaces;
- case 2d: wooden frames with Kr interspaces.

Determining heat transfer coefficients U at the window level was carried out on Lesosai computer program, using the data base for frame and Glazing Library. A detail concerning the characteristics of a window (case 2a) is given in Figure 6 and the variation of heat transfer coefficients in Figure 7.



Surface area [m²] 5,5

Glazing type: ☐ Triple vetroTherm 1.1 2x couche low-E 4/16/4/ U [W/m²K] 0,600 Gp/Fs [-] 0,500

Frame kind: ☑ U-value frame [W/m²K] 0,7 Carpentry PVC

Frame fraction [%] 21,3

Cavity spacerbar: [m] 12,7 Linear coeff. ψ [W/m·K] 0.032

Glazing Ug value: 0,6 [W/m²K]

Uf frame coef.: 0,7 [W/m²K]

Global U value 0,696 [W/m²K]

Thermal bridges

(1)	2,22 [m]	0,023 [W/m·K]
(2)	4,92 [m]	0,023 [W/m·K]
(3)	2,22 [m]	0,023 [W/m·K]

Fig. 6. *Detail of the characteristics of a window (case 2a) [7]*

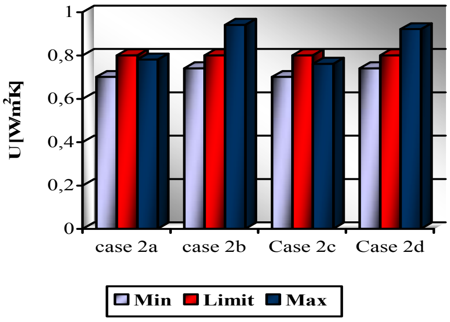


Fig. 7. *Values of heat transfer coefficient*

One notices that the lowest heat transfer coefficient was obtained in the case of using the PVC frames, as a result of a better coefficient (U_f=0.7 W/m^{2}K) and filling the interspaces with Kr (U_g=0.5 W/m^{2}K) (case 2c).

For the model house under consideration, both in case 2a and 2c (PVC frames with interspaces filled with Ar and Kr) heat transfer coefficients U≤0.8 W/m^{2}K were obtained for all windows, in conformity with limits imposed to passive houses.

Performing an ecological analysis (Figure 8) from the point of view of the impact of windows upon energy consumption and toxic emissions it followed that the highest weight on the two impact indicators comes with the materials from which the frames are made, namely PVC (2547 MJ/year and 146.92 kg CO_2-eq/year), while the contribution of the window glazing to energetic consumption and polluting emissions is minimum (253.8 MJ/year and 16.23 kg CO_2-eq/year).

4. Conclusions

Considering that energetic and ecological performances of buildings primarily depend on the designing solutions of envelope, in order to build a passive house in a certain climatic zone, its envelope should be so designed that it complies with the climatic variations by providing the energy needs imposed. For climatic zone III one recommends the use of some very good heat insulating materials - for opaque elements with an impact as low as possible upon environment, the U coefficients at wall/roof/floor slab level should be limited to 0.11/0.10/0.10 W/m^{2}K; for windows - the use of triple glass panes window of low emissivity, interspaces filled with Ar and Kr, warm edge spacers and PVC or wood frames.

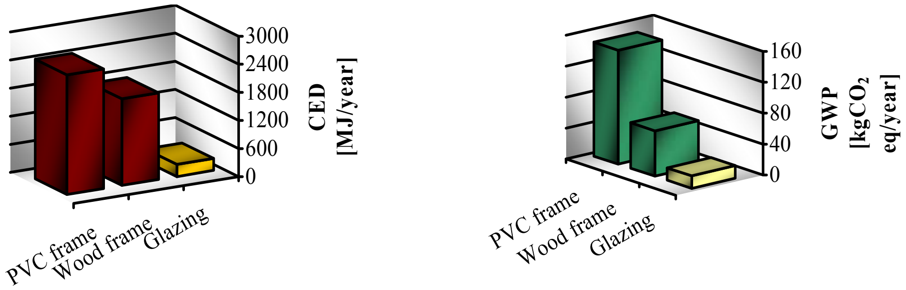


Fig. 8. *Influence of window frames upon CED and GWP indicators*

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