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EVALUATION OF NATURAL CLIMATIC CONDITIONS IN REALIZED ENERGY EFFICIENT BUILDINGS

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Abstract:
The analysis and evaluation of the features of spatial architecture layout design, structural and engineering solutions of modern energy-efficient low-rise residential buildings have been conducted, taking into account the climatic zoning of the Earth. Research methods are based on a comparative analysis of the modern case studies focuses on the construction of energy-efficient low-rise residential buildings. A number of studies have been devoted to the problem of designing energy-efficient passive houses in a climate like Ukraine, but there is still no common typological basis for designing. Further studies have focused on implementing the passive house standard, as well as realized passive house projects have been launched in different parts of the world. This experience is considered as an example of project practices and norms of Europe, Asia, and Arab countries. These examples were grouped by climatic conditions and analyzed from the point of view possibilities of adopting their feasibility solutions to the particular Ukrainian climate and conditions.

Keywords: Energy Efficient Design; Modern Low-Rise Residential Buildings; Architecture; Structural and Technical-Engineering Solutions; Climate Zones.

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1. Introduction

Following the first oil crisis in 1973, much attention was paid to the design of energy-efficient buildings around the world. The first energy-efficient buildings appeared in the UK, Finland, Germany, and the USA. There are common solutions amongst the principles of energy efficient building design that minimizes the energy consumption of the buildings, although depending on the climatic conditions of the country applicable to the buildings construction and locality. Therefore, it is an important task to determine the impact of climatic considerations on the spatial architecture layout design, structural and technical-engineering solutions of such buildings.

2. Materials and Methods

In this article, a number of scientific studies, dissertations, scientific publications, conference materials acknowledging energy-efficient buildings as well as normative documents in various countries of the world, were reviewed in order to analyze and evaluate the features of spatial

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architecture layout design, structural and engineering solutions of modern energy-efficient low-rise residential buildings. The research method is a comparative analysis and was conducted in order to evaluate the performance of the spatial architecture layout design, structural and technical engineering solutions of energy-efficient buildings in different climatic conditions. Analysis of the climatic conditions of Ukraine and development of recommendations to assess the performance of different solutions in the conditions of Ukraine.

In May 1988, W. Feist (Germany) and B. Adamson (Sweden) developed the concept of a "Passive House" (passive house). The theoretical proof for the feasibility of such houses was provided in the thesis, "Passive Houses in Central Europe" through computerized simulations of the energy balance of buildings [1].

3. Design Feature Analysis of Energy-Efficient Buildings in Countries with Different Climates

In order to achieve the level of comfort and the low life-cycle costs, the thermal quality of the components used in Passive Houses must meet stringent requirements. These requirements are directly derived from Passive House criteria for hygiene and comfort as well as from feasibility studies. Therefore, the Passive House Institute developed recommendations on Passivhaus climate zone certification criteria are valid for the respective indicated climates and climates with fewer requirements. These climate zones are as shown on photo 1 [2].

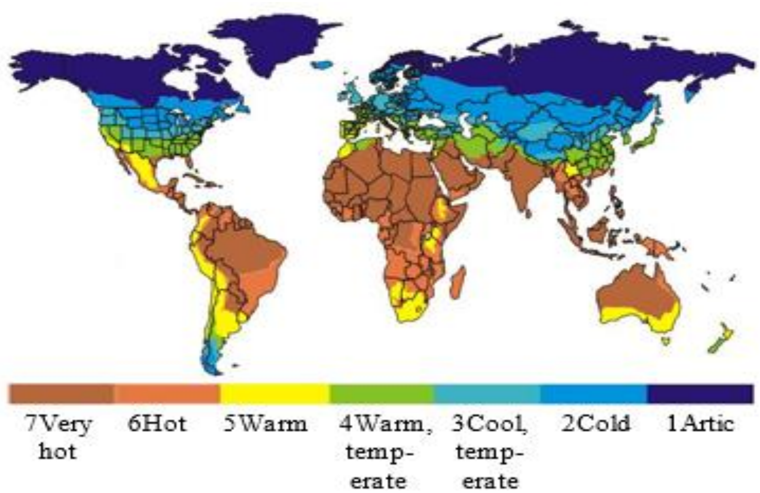

Photo 1: Passivhaus climate zones

There are many scientific research and realized projects which address the topic of Passive House in modern international construction practice. Currently, there are more than 50,000 Passivhaus' (Passive House) in the world have been built and realized [3], in Ukraine – 2 houses) [4].

3.1. Arctic Climate

The features of spatial architecture layout design, structural and technical-engineering typological requirements for passive residential buildings in arctic climates are shown in photos 2-3. The outcomes of the thesis [5] showed that the construction of passive houses is unreasonable to

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completely fulfill the fundamental definition of a passive house in arctic climate areas. This is due to the increase in capital costs, which cause a costly upfront investment in energy efficiency measures including structural and technical engineering solutions that allows for dramatic reduction in the traditional heating costs. However, the payback period will take a very long life span due to the addition of higher investment costs in energy efficiency measures in this area.

Photo 2: South and east prospect

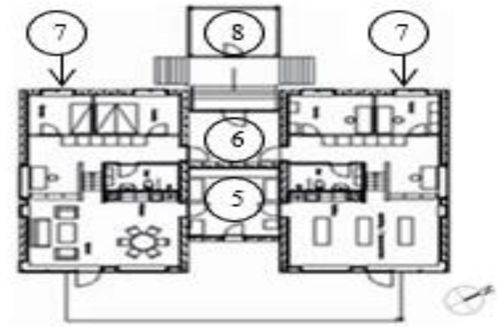

Photo 3: Ground floor plan

1 – Elevated foundation due to the wind and snow drifting and thawing of permafrost, acts as an additional buffer space reducing reduce heat losses through the building envelope; 2,3 – south-east oriented windows of the indoor living areas of the apartments are considered favorable for passive solar heating gains; 4 – use attic acts as buffer zones between the interior and outdoor climate; 5 – unheated sunspace in the south side of the house included within the volume of the building, which is considered as a source providing space heating, also can preheat ventilation air and reduce transmission of external noise; 6 entrance to the building is considered through tambour in the north side of the building are considered favourable in order to utilize the solar gains for space heating in the indoor living areas along the southern side of the building; 7 – north oriented living areas along the façade is irrational due to the solar irradiance and the windows of the indoor living areas of this facade is considered irrational due to winter wind and heat loss through the windows in winter; 8 –garage and technical room in the north side of the house acts as additional buffer zones protecting the indoor living areas from the prevailing winter winds.

3.2. Cold Climate

In Finland, the passive house standard was modified to cope with the cold climate. The main typological requirements for passive houses in Finland were developed in [6], which photos 4-5 illustrate.

Photo 4: South and west prospect

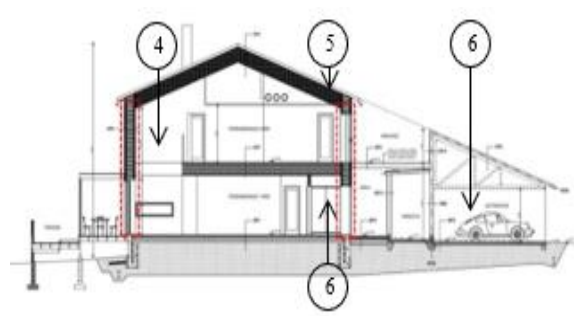

Photo 5: Cross section

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1 – Compact house, with south-east oriented windows of the indoor living areas of the apartments are considered favorable for passive solar heating gains; 2,3 – horizontal overhang, removable shutter, and fixed louver in the south-west façades allow the solar radiation to reach the building in winter and at the same time block the radiation in summer; 4 – roof lighting; 5 – sloping roof; 6 – unheated cloak-room in north side acts as buffer zone protecting the indoor living areas from the prevailing winter winds; 7 – unheated garage and technical room in the north side of the house acts as additional buffer zones protecting the indoor living areas from the prevailing winter winds.

In Northern Europe, specifically in Sweden and Denmark, masters and doctoral dissertations were carried out in Lund University (Sweden) with the focus on the feasibility of passive house standard for cold climate zones. The outcomes of the studies indicated the rationalization of structural and technical-engineering solutions that were incorporated in passive house design [7-9].

3.3. Cool, Temperate Climate

Considerable studies were devoted to passive houses in a cool temperate climate. This is due to the fact that the passive houses were originally designed and built in such a climate. The passive house approach has been tested and evaluated in various locations within Europe. Within the EU-funded project of CEPHEUS (Cost Efficient Passive Houses as European Standard) and the European Thermie programme, 14 different European locations were constructed according to passive house standards [10]. In this research, the main typological requirements for passive houses in this climate were developed. They are presented in the photos 6-7.

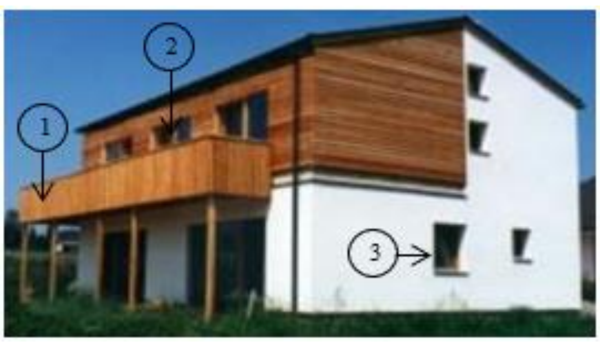

Photo 6: South and east prospect

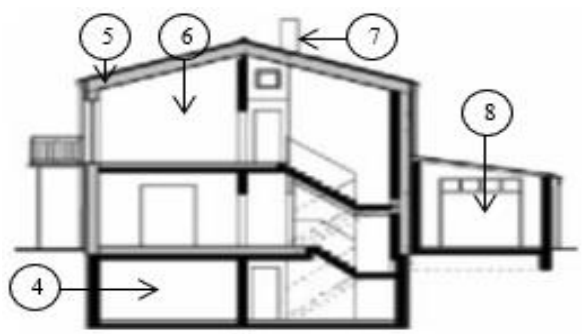

Photo 7: Cross section

1 – Window ledge and horizontal overhang in the south-west façades allow the solar radiation to reach the building in winter and at the same time block the radiation in summer; 2,3 – compact house, with the south-east oriented windows of the indoor living areas of the apartments are considered favorable for passive solar heating gains; 4 – basement acts as a buffer space reducing reduce heat losses through the building envelope; 5 – sloping roof; 6 – attic premises that occupy the roof space; 7 – fireplace that take part in the heating of the house; 8 – unheated garage and technical room in the north side of the house acts as additional buffer zones protecting the indoor living areas from the prevailing winter winds.

Similar studies to test the possibility of passive houses construction in cool temperate climate were devoted [11-16].

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The first passive house in Poland was built as a result of the development of dissertations [11]. Photos 8-9 present the main typological requirements for passive houses development in these works. It **was** noted that the cost of passive house construction is about 37% per m^2 higher compared to the standard house, whereas the estimated time of the investment return is 20-30 years.

Photo 8: South and east prospect

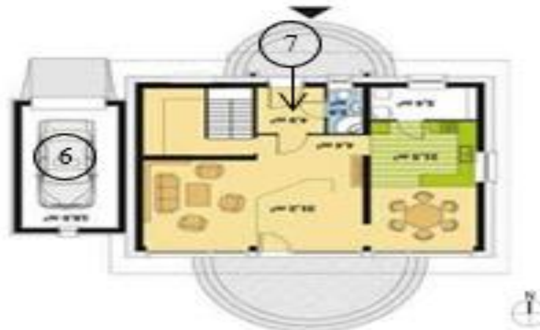

Photo 9: First floor plan

1,2 – Compact house, with the south-east oriented windows of the indoor living areas are considered favorable for passive solar heating gains; 3 – horizontal overhang and internal blinds allow the solar radiation in the south-west façades to reach the building in winter and at the same time block the radiation in summer; 4 – dormer window; 5 – attic premises that occupy the roof space; 6 – placement of unheated garage in the west side of the house acts as additional buffer zones protecting the indoor living areas from overheating during the summer time; 7 – entrance to the building is considered through tambour in the north side of the building are considered favorable in order to utilize the solar gains for space heating in the indoor living areas along the southern side of the building.

Typological principles for designing low and medium rise energy-efficient residential buildings in the climatic conditions of the Middle Volga region were developed in dissertations [12-13]. It had been studied the architectural integration of renewable energy sources into low-rise residential buildings.

In Denmark, the issue concerning the architectural quality of passive houses was investigated in terms of optimizing energy consumption and its impact on the indoor microclimate [14]. The results presented in this study show that the most rational form of detached single-family houses is a cube. It had been determined the rational location and area of the transparent parts of the envelope of energy-efficient buildings for different sides of the horizon, as well as the rational use of sun protection. An integrated approach was proposed in [15] with the purpose of experimenting the possibility of passive house dwellings construction with locally available and generally sustainable materials.

Feasibility analysis investigates the possibility of developing passive house under the natural-climatic conditions of China was devoted to the master's work [16]. The analysis was based on economic and technology aspects combined with the mature experience from the design passive house projects in Europe.

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A parametric analysis of the potential effects of predicted climate change on the performance of a house designed to passive house standards was carried out in Ireland [17]. Study has shown that with increasing atmospheric temperature in Ireland, the achievement of the passive house standard has been completed on a growing number of Irish houses, even despite a slight increase in the cost of measures in preventing overheating in summer.

A study had been undertaken with the main concern of utilizing the solar energy as one of the ways to solve the energy supply in passive houses in Belgium [18]. The question of determining the optimal location of solar collectors in cool temperate climate in a number of cities in European countries was investigated in [10]. The study showed that the optimal orientation in all cities is southern, and the tilt angle depends both on the geographical latitude and the degree of cloudiness of the sky and its annual span.

3.4. Warm, Temperate Climate

An existing passive house building in Spain was used as models with the aim to analyze the typological requirements in a warm temperate climate are presented in photos 10-11. The extra costs of a passive house in a warm temperate climate are 5 %, in comparison with the standard house with a payback period of 5 years [19].

Photo 8: South and east prospect

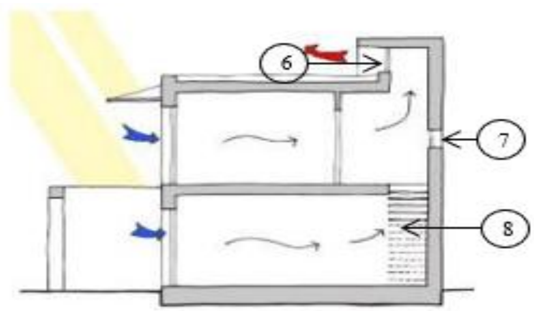

Photo 11: Summer lighting-ventilation strategy

1 – Compact house, with unheated glazed balcony in the west side of the house acts as additional buffer zones protecting the indoor living areas from overheating during the summer time; 2,4 – fixed louver and horizontal overhang in the south façade allow the solar radiation to reach the building in winter and at the same time block the radiation in summer; 3 – south-east oriented windows of the indoor living areas are considered favorable for passive solar heating gains; 5 – flat rooftop terrace; 6 – South oriented long window in the top of the stairs allows the natural lighting of this north zone ; 7 – north oriented vent openings considered to achieve an additional natural ventilation; 8 – north space in the stairs acts like a chimney that allows the air extraction during the summer night-time ventilation.

On the other hand, similar requirements for passive houses design in New Zealand are developed in [20]. The difference is that north-facing windows of the living rooms are frequently lead to overheating of the premises during the summer season. In order to prevent overheating, solar shading devices have to be designed in order to prevent overheating, while in the southern hemisphere solar paths are inclined to the north.

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3.5. Warm Climate

Photos 12-13 show the general typological requirements for passive houses in a warm (subtropical) climate and the studied process of implementing the project "Passive On" [21]. These requirements had been proposed and implemented in the strategy of passive houses design in Italy, are shown in photos 10-11. The outcomes of the study indicate that the payback period of the passive house in Italy is 20 years.

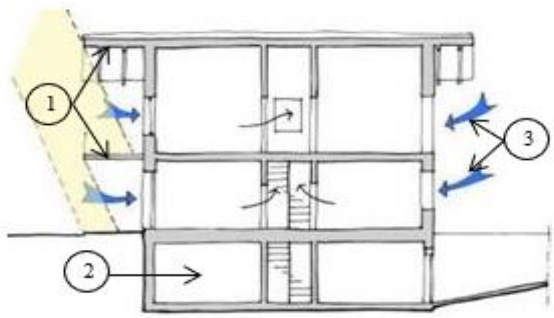

Photo 12: Summer ventilation strategies

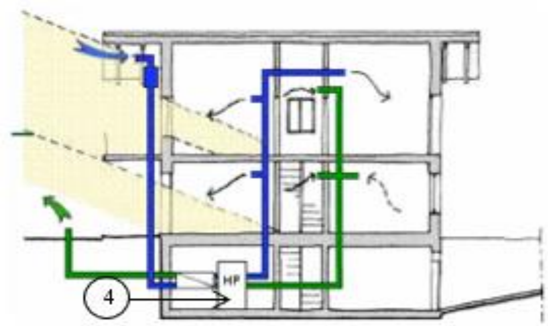

Photo 13: Winter ventilation strategies

1 – Window ledge and horizontal overhang in the south-west façades allow the solar radiation to reach the building in winter and at the same time block the radiation in summer; 2 – basement acts as a buffer space reducing reduce heat losses through the building envelope; 3 – natural cross-ventilation of buildings; 4 – active ventilation with heat recovery from exhausted air.

3.6. Hot Climate

The passive house example in Mexico that demonstrated the analysis of typological requirements in a hot climate is presented in photos 14-15. The outcomes of the analysis indicated that there are no particular differences with passive houses in a warm climate [22].

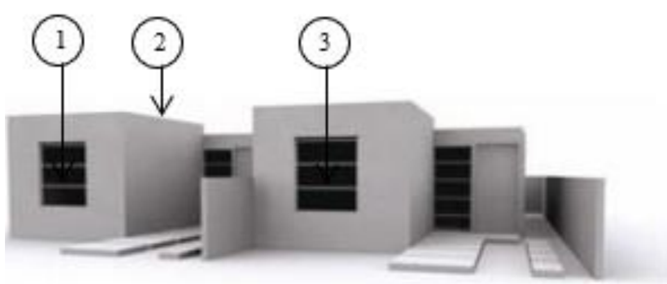

Photo 14: South and west prospect

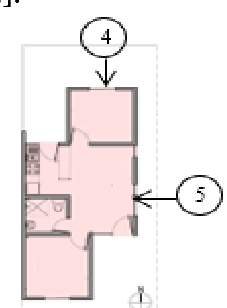

Photo 15: Ground floor plan

1,5 – South-west oriented windows of the indoor living areas are considered favorable for passive solar heating gains; 2 – flat rooftop terrace; 3 – removable shutter in the south façade allow the solar radiation to reach the building in winter and at the same time block the radiation in summer; 4 – north oriented living areas along the façade is irrational due to the solar irradiance and the windows of the indoor living areas of this facade is considered irrational due to winter wind and heat loss through the windows in winter.

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3.7. Very Hot Climate

An interesting study demonstrated the development of the typology of passive house dwellings concept in the very hot climate region in Dubai, the United Arab Emirates which photos 16-17 illustrate. The outcomes of the project showed that vernacular houses attributes are widely integrated into the main typological requirements for contemporary design of the passive house dwellings [23].

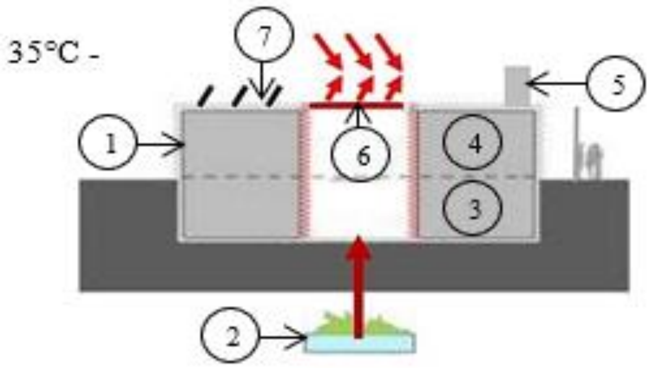

Photo 16: Cross section

Photo 17: Ground floor

1 – thermal envelope includes various insulation material types and thicknesses to reach high levels of airtightness and reduce heat gain to the minimum; 2 – evaporative cooling integrated into the design of the main courtyard to provide added protection against the high insolation levels; 3 – basement level included the bedroom spaces directed towards the main courtyard; 4 – ground floor incorporated the living and guest spaces directed towards the main courtyard; 5 – rooftop building access stair exit; 6 – moveable white membrane atrium protecting from overheating; 7 – flat rooftop holds thermal solar system solar water heating system to increase its energy effectiveness; 8 – courtyard resembles the heart of the house and the shaded courtyards and their micro-climates produce thermal comfort and air circulation.

4. Climate Analysis of Ukraine

A new climatic zone of the territory of Ukraine [24], developed with the participation of the author of this article, identifying five climatic zones on the territory of Ukraine, that includes: I - North-Western, II – South-East, III - Carpathians, IIIA - Gorno-Carpathian, IIIB - Transcarpathia, IV - Southern Coast of Crimea, V - Crimean Mountains, as seen in the photo 18.

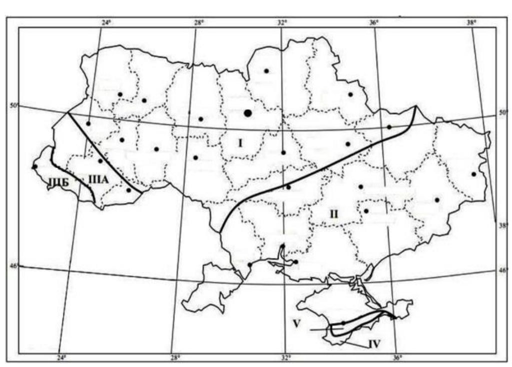

Photo 18: Climate zones of Ukraine map

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Table. 1 contains the climatic characteristics of each zone. This zoning is the basis for the development of typological requirements for passive house dwellings in Ukraine.

Table 1: Climate date of zones and subzones

Climate Zones		Ambient temperature, °C				Average annual precipitation, mm	Relative humidity in July, %	Wind speed in January, m/s
		Average		Absolute				
		January	July	Minimum	Maximum			
I		From -5 to -8	From 18 to 20	From -37 to -40	From 37 to 40	From 550 to 700	From 65 to 75	From 3 to 4
II		From -2 to -6	From 21 to 23	From -32 to -42	From 39 to 41	From 400 to 500	< 65	From 4 to 6
III	IIIA	-7	14	-38	35	1600	From 77 to 81	3
	IIIB	-4	19	-32	39	1000	> 70	3
IV		3	23	-20	39	600	< 60	4-5
V		-4	16	-27	32	1060	70	4-5

According to the Passivhaus climate zone certification criteria, Ukraine falls within the "cold and cool, temperate" climate classification. Therefore, when developing typological features of passive house dwellings design in Ukraine, one should proceed from the experience of building such houses, discussed in sections 3.2-3.3. Certain design features of such houses in Ukraine is listed in conclusions.

5. Conclusions

It will be necessary to take into consideration the following basic features that distinguish passive house design in Ukraine:

- The orientation of the house is latitudinal;
- Compact form with compositional geometrical typology solutions will help passively in reducing the internal heating and cooling loads;
- Absence and restriction of windows in the North side of the buildings in order to reduce heat loss from buildings caused by winds. Placement of the tambour, unheated garage and technical room in the North side of the buildings, are considered as buffer zones;
- The windows of the indoor living areas along the south oriented façade of the building are considered favorable for space heating by letting solar radiation in through windows. In order to prevent overheating, solar shading devices have to be designed in a selective way, thus they should allow radiation to reach the building in winter and at the same time, block the radiation in summer;
- The premises that are located on the west side of the buildings should be protected from summer overheating by solar shading system;
- According to the Passivhaus climate zone certification criteria for a specific zone in Ukraine, opaque buildings envelope are expected to achieve thermal resistance values [R-values] of 8.3 m2·K/W for the exterior building component in cold climate and 6.7 m2·K/W in cool, temperate climate. Glazed surfaces in cold climate are expected to achieve R-values of 1.5 m2·K/W for vertical glazed surfaces, 1.4 m2·K/W for inclined glazed surface, 1.3 m2·K/W for horizontal glazed surfaces and 1.0 m2·K/W for inclined glazed surface, 0.9 m2·K/W for horizontal glazed surfaces in cold temperate climate [2];

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- Utilizing ventilation air subsoil heat exchanger for air preheating/cooling with solar thermal water heating.

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