УДК 621.311.: 620.97: 697:329 https://doi.org/10.36296/1819-8058.2025.2(81).133-139

EFFICIENCY OF SOLAR-PASSIVE STRUCTURES MADE FROM STRAW ADOBE BLOKS ACROSS REGION OF UKRAINE

Received May 05, 2025; accepted Jun. 27, 2025
Available online Jun. 30, 2025

Kyrnos L.[1], Zaks H.[2]

Author for correspondence: Kyrnos Larysa,
e-mail: larakirnos@gmail.com

[1] Chief Architect of the project
https://orcid.org/0000-0003-2503-3071

[2] Student
http://orcid.org/0009-0001-4532-1671

[1] Institute of Renewable Energy, National Academy Of Sciences Of Ukraine,

[2] Los Altos High School, CA, USA

Abstract. *This study presents an analysis and assessment of the annual levels of solar radiation and the duration of sunshine across the regions of Ukraine. It establishes that these parameters are sufficient to achieve a level of energy efficiency in solar-passive external wall structures that ensures a stable reduction in energy consumption for heating low-rise residential buildings constructed from straw adobe blocks.*

The research identifies key factors influencing the effectiveness of straw and clay adobe block use across Ukrainian regions, namely:

- *The climatic conditions of the region;*
- *The seasonal gross yield of straw;*
- *The cost of primary building materials (clay and straw), as well as the costs associated with transportation and storage under forced ventilation conditions.*

It was determined that the territory of Ukraine can be conditionally divided into three zones with high, medium, and low efficiency of adobe-clay block use for low-rise residential construction.

Keywords: *straw adobe blocks; efficiency of use; solar-passive wall design; thermal resistance of exterior walls; economic-regional factor.*

Introduction

The restoration of low-rise residential buildings in Ukraine's private households requires addressing numerous challenges, including a shortage of human resources and building materials, a high demand for heating energy, and existing developments with low energy efficiency, which contribute to increased CO_2 emissions. These challenges can be mitigated through the following measures:

– ensuring environmentally friendly housing development by utilizing local, inexpensive materials in combination with accelerated construction technologies;
– applying energy-efficient external wall structures that integrate both accessible local materials and advanced materials enhanced in thermal performance;
– reducing energy consumption through passive solar heating constructions integrated into the external walls of buildings.

Energy Efficiency of Adobe-clay Block in Single-story Residential Construction

This article evaluates the effectiveness of using adobe blocks for solar-passive and thermally stable external wall structures in low-rise residential construction, ensuring an energy efficiency level that meets the standards of passive houses under the requirements of the European Union Directive (EU/2024/1275), as well as the national energy efficiency policy of Ukraine [1- 4].

To determine the energy efficiency of adobe-clay block enclosing structures, a single-story residential building is considered as a single heated volume enclosed by slabs and thermal-protective walls, which are constructed from the following energy-efficient structures:

1) One wall, oriented southward, serves as a solar-passive enclosing structure that generates low-potential thermal energy from solar radiation and accumulates it within the adobe-clay block wall mass [13]. The external surface of the wall is plastered and painted black to maximize solar absorption. Additionally, enclosed air layers are attached to the wall surface, bounded externally by transparent glass or plastic covers.
2) The other external walls serve as thermal-protective enclosure structures constructed from adobe blocks with optimized thermal properties that meet European passive house standards [3,14-15].

Determination of Thermal Resistance of Energy-Efficient Thermal-Protective Enclosing Structures

The heat-shielding enclosure proposed in this study has to satisfy the following condition [14]:

$$R_{\Sigma np} \geq R_{q\,min}\,, \tag{1}$$

where $R_{\Sigma пр}$ is the calculated adobe blocks, and thermal resistance of the energy-efficient enclosure Structure made from R_{qmin} is the minimum (normative) thermal resistance of the reference enclosure structure. According to the EU standards for nearly zero-energy buildings [3, 4], and the Ukrainian construction norms DBN B.2.6-31:2021, the minimum required thermal resistance of an external wall is:

R_{qmin},= $4,0\ m^2 \cdot K/W$ for Building-Climate Zone I;

R_{qmin},= $3,5\ m^2 \cdot K/W$ for Building-Climate Zone II.

Calculations for adobe-clay block enclosure structures with various wall thicknesses (0.51 m; 0.40 m; 0.34 m) confirm that the proposed structures satisfy the normalized requirements of thermal resistance [14,15]. The structure consists of multilayer walls with plane-parallel layers (from interior to exterior:

1. Adobe-clay block masonry on adhesive, with a density of $\rho_{гсб} = 1000\ kg/m^3$, and thermal conductivity $\lambda_{гсб} = 0,77\ W/(m\cdot K)$, with wall thicknesses $\delta_1 = 0,4\ m$; $\delta_2 = 0,51\ m$; $\delta_3 = 0,34\ m$.
2. Insulation layer made of mineral wool boards on synthetic binder, with density $\rho_{тш}$, = $70\ kg/m^3$, thermal conductivity $\lambda_{тш} = 0,039\ W/(m\cdot K)$, and thickness $\delta_1 = 0.15\ m$.
3. Ventilated air layer with density $\rho_п = 1,247\ kg/m^3$ (at 10 °C), thermal conductivity $\lambda_п = 0,0026\ W/(m\cdot K)$, and thickness $\delta_p = 0.05\ m$.
4. External finishing with siding panels.

We use the following formula to obtain the heat transfer resistance $R_{гсб40}$ of the heat-shielding enclosure structure [6,7, 9, 14] made of adobe blocks with a masonry width of 0.4 m, a thickness of the heat-insulating layer of 0.15:

$$\mathrm{R}_{et} = \frac{1}{\alpha_{вн}} + \sum_{i=1}^{n} \frac{\delta_i}{\lambda_{i0}} + \frac{1}{\alpha_{зв}} = 0,1119+0,519+3,846+0,0435 = 4,520\ m^2\cdot K/W \quad (1)$$

where $\alpha_{вн}$, $\alpha_{зв}$ – heat transfer coefficients of the inner and outer surfaces of the enclosing structure, $W/(m^2 \cdot K)$; δ_i – thickness of the first layer of external walls, m; λ_{ip} – calculated thermal conductivity of the material of the first layer of external walls in the design, $Вт/(м\cdot К)$. So we conclude that, $R_{гсб40} = 4,520\ m^2\cdot K/W$, which meets the regulatory requirements as per DBN V. 2.6-31:2021 "Thermal insulation and energy efficiency of buildings".

According to formula (1), the heat transfer resistance of the enclosing structure made of adobe blocks with a masonry width of 0.51 m, the thickness of the heat-insulating layer is 0.15 m is $R_{гсб51} = 4,663\ м^2\cdot К/Вт$, that meets regulatory requirements.

According to formula (1), the heat transfer resistance of the enclosing structure made of adobe blocks with a masonry width of *0.34 m*, the thickness of the heat-insulating layer is *0.15 m* is $R_{гсб51} = 4,663\ м^2\cdot К/Вт$, that meets regulatory requirements.

Table 1. Dependence of the width of the masonry of external walls on solar energy parameters by regions of Ukraine

Name of the solar energy region	**Annual total solar radiation, *kWh/m²***	**Hours of sunshine per year (hours per year), *hours***	**The width of the masonry, *B, m***	**Administrative regions of Ukraine that belong to the solar energy regions**
1st Solar Energy Region	1400 - 1250	2400 -2000	0,34	Odesa, Mykolaiv, Donetsk, Kherson, Dnipropetrovsk, Kherson, Дніпропетровська
2d Solar Energy Region	1250 -1125	2000 -1900	0,40; 0,45	Zaporizhzhia, Luhansk, Kharkiv (0.45 m), Poltava, Cherkasy, Zakarpattia, Kirovohrad, Vinnytsia, Khmelnytskyi (0.45 m)
3d Solar Energy Region	1125 - 1070	1900 - 1800	0,51;	Kyiv, Chernihiv, Sumy
			0,52;	Ternopil
			0,54	Lviv, Ivano-Frankivsk, Volyn, Rivne, Chernivtsi, Zhytomyr

In Table 1 shows the dependence of the width of masonry of external walls on solar energy parameters [5] by regions of Ukraine: indicators of annual total solar radiation (kWh/m²); duration (per year) of sunshine in hours. When analyzing the amount of annual total radiation [5, 9, 11] inflow to the territory of the regions of Ukraine, we observe that its largest amount (*1400-1250 кВт·год/м²*) is received in the southern regions, which we refer to the I solar energy region; average amount (*1250-1125 kWh/m²*) – in the central and eastern regions (II solar energy region); the smallest amount is in the western and northern regions (*1125 – 1070 kWh/m²*), which are assigned to the III solar energy region). The width of the masonry of external walls made of adobe blocks is determined by the region the building is constructed.

Efficiency of the Use of Straw Adobe Blocks by Regional and Climatic Factors

The paper considers the effectiveness of using adobe blocks (with a filler - wheat, barley straw) with a density of

1000 kg/m^3 with a straw content of 20%. The effectiveness across the different administrative regions of Ukraine is impacted by the following factors:

1. The required width of the masonry of the outer wall made of adobe blocks, *(B, m*).
2. The period of their production (month).
3. Cost (m_1, *UAN*) and physical characteristics of the main building materials (clay, straw).
4. Cost of transportation of raw materials to the production and use site,. (m_2 *UAH*).
5. The cost of storing straw in warehouses with forced ventilation, (m_3 *UAN*).

The efficiency of using straw adobe blocks in the territories of the regions of Ukraine is determined by the economic and regional factor *N UAH/m^2*, which takes into account the amount of material costs for the manufacture of 1 m^2 of the façade of the external wall from adobe blocks in accordance with different climatic and economic conditions in the regions of Ukraine. The *N* indicator is determined by the following formula:

$$N(UAH/m^2) = m_1(UAH/m^2) + m_2(UAH/m^2) + m_3(UAH/m^2); \quad (2)$$

$$m_1(UAH/m^2) = m_c(UAH/m^2) + m_г(UAH/m^2). \quad (3)$$

The volume and weight of the main components of adobe blocks (clay, straw) is determined using the width of the masonry of the outer wall of the building (B, m) and the density of the blocks - 1000 kg /m^3, with 20% straw content.

The width of the adobe block must meet the requirements for the standardized heat transfer resistance index of the external enclosing structure of the house, which for the I climatic zone is calculated as $R_{q\,min}$, $= 4{,}0\ (m^2 \cdot K/W)$; for the II climatic zone is calculated as $R_{q\,min}$, $= 3{,}5(m^2 \cdot K/W)$ according to DBN V. 2.6-31:2021.

Below is the detailed breakdown of the parameters and cost metrics used:

– *B* is the width of the masonry of the outer wall of the building (m) as determined by the thermophysical characteristics of the materials and by the climatic characteristics of the area of use;
– m_1 consists of the cost *(UAH/m^2*) of the main building materials (clays $m_г$, straw m_c);
– m_2 is the estimated cost (*UAH/m^2*) of transportation of raw materials. We assume that the production and use sites are co-located to lower overall transportation costs and the environmental impact of transportation. Red building clay is a fairly common building material in Ukraine, the delivery of which can be within 5-10 km. Straw is the key material that impacts the transpiration cost. In areas with a high yield of grain crops (wheat, barley) we assume transportation distance of up to 10 km. In areas with a low yield of grain crops (where the gross harvest of straw is not more than 700 thousand tons), the straw is delivered from neighboring regions;
– m_3 - cost (UAH) of straw storage in warehouses with forced ventilation.

The paper discusses two modes of production of adobe blocks [10]:

- 1 mode – from straw, which is used to manufacture adobe blocks during the harvest period of grain crops (months: June, July, August);
- 2 mode – from straw, which is stored in ventilated warehouses (months: September, October, November).

In December - May, it is not rational to make adobe blocks, since the quality of straw deteriorates significantly, and the drying conditions of the material also deteriorate. According to this indicator *N*, it is possible to determine the feasibility of using adobe blocks in different regions of Ukraine, depending on climatic conditions and yield [10-12] of grain crops (wheat, barley) in these regions.

In Table 2 shows the main indicators of the efficiency of the use of adobe clay blocks (in June, July, August), and in Table 3 the same indicators, but for September, October, November.

Cost indicators:

1. Cost of primary raw materials:

– construction clay when delivered at a distance of up to 10 km, by a truck with a dump truck Kamaz 10 tons - 4200 UAH; for delivery up to 20 km - 7900 UAH [Electronic resource]: htpps//samosval.ddp.ua;
– clay is readily available in all regions, we assume it's transported locally;
– straw in bales weighing 15 kg - 25 UAH/piece (when straw can be cheaply stored under cover - in June, July, August) [Electronic resource]: htpps //flagma.ua

2. Transportation of straw up to 5 tons – 23 UAH/km, [Electronic resource]: htpps //saf.org.ua;
we assume average distance of 10 km within each region and use Google Maps APIs to calculate distance between regions when straw is transported between different regions, using the following software [Electronic resource]: (https://github.com/syzygy137/Ukraine-Regions).

3. The cost of storing straw in warehouses with forced ventilation was determined as an average statistical value and amounted to up to 1% of the cost of straw.

4. The indicator of the gross straw harvest was determined according to statistical data [12] for 2021.

We developed a software tool ([Electronic resource]: https://github.com/syzygy137/Ukraine-Regions) to calculate straw transportation costs for use in the production of adobe by using an Integer Linear Programming (ILP) solver. The program is used to determine optimal straw transportation routes. The tool integrates Google Maps API to estimate travel distances between regions. Our analysis shows that for small to medium-scale adobe block production, straw supplies can be locally sourced or imported from nearby high-yield regions without competition. The routes for low contention case are listed in Table 4. Once the total production scales to approximately 5,000,000 m² across Ukraine (enough to build around 33,000 single-story homes, each requiring 150 m² of adobe blocks), we begin to observe gradual resource contention as the necessity for low grain yield regions to import straw from more distant regions arises as shown in graphic (Figure).

Table 2. Main indicators of the efficiency of the use of adobe blocks (in June, July, August)

Region of Ukraine	Masonry width, *B,* м	Gross straw harvest, *thousand tons*	Distance to straw production site *(km)*	Cost* of straw, m_c *(UAH/м²)*	Cost* of construction clay, $m_г$ *(UAH/м²)*	Cost* of basic materials in blocks, m_1, *(UAH/м²)*	Cost* of straw transportation, m_2, *(UAH/м²)*
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Vinnytsia	0,40	1458,6	10	80/133,33	320/134,40	267,73	3,68
Volyn	0,54	550,00	168.35	108/180,0	432/181,44	361,44	83,64
Dnipropetrovsk	0,34	2433,60	10	68/113,33	272/114,24	227,57	3.13
Donetsk	0,34	1107,10	10	68/113,33	272/114,24	227,57	3,13
Zhytomyr	0,54	521,80	127.81	108/180,00	432/181,44	361,44	63,50
Transcarpathian	0,40	1043,50	10	80/133,33	320/134,40	267,73	3,68
Zaporizhzhia	0,34	536,50	85.15	68/113,33	272/114,24	227,57	26,63
Ivano-Frankivsk	0,54	201,50	132.38	108/180,00	432/181,44	361,44	65,77
Kyiv	0,51	780,40	10	102/170,00	408/171,36	341,36	4,69
Kirovohrad	0,40	1401,70	10	80/133,33	320/134,40	267,73	3,68
Luhansk	0,40	695,80	155.04	80/133,33	320/134,40	267,73	57,05
Lviv	0,54	587,6	127.77	108/180д,00	432/181,44	361,44	63,48
Mykolayiv	0,34	1859,3	10	68/113,33	272/114,24	227,57	3.13
Odessa	0,34	2414,6	10	68/113,33	272/114,24	227,57	3,13
Poltava	0,40	890,7	10	80/133,33	320/134,40	267,73	3,68
Rivne	0,54	415,0	159.94	108/180,00	432/181,44	361,44	79,46
Sumy	0,51	615,7	176.47	102/170,00	408/171,36	341,36	82,80
Ternopil	0,52	849,1	10	104/173,33	416/174,72	348,05	4,78
Kharkiv	0,45	1870,0	10	90/150,00	360/151,20	301,20	4,14
Kherson	0,34	1395,1	10	68/113,33	272/114,24	227,57	3,13
Khmelnytskyi	0,45	954,2	10	90/150,00	360/151,20	301,20	4,14
Cherkasy	0,40	817,7	10	80/133,33	320/134,40	267,73	3,68
Chernivtsi	0,54	140,6	171.03	108/180,00	432/181,44	361,44	84,97
Chernihiv	0,51	588,4	148.35	102/170,00	408/171,36	341,36	69,61

***** *the cost indictor represents 1 m² of the adobe masonry wall*

Table 3. Main indicators of the efficiency of the use of adobe blocks (in September, October, November)

Region of Ukraine	The width of the masonry, *B, m*	Gross straw harvest, *thousand tons*	Cost* of straw, m_c, (*UAH/м²)*	Cost* of construction clay, $m_г$, (*UAH/м²)*	Cost* of basic materials, m_1, (*UAH/м²)*	Cost* of straw transportation, m_2, (*UAH/м²*	Cost* of straw storage in warehouses, m_3, (*UAH/м²)*
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Vinnytsia	0,40	1458,6	80/ 133,33	320/134,40	267,73	3,68	2,68
Volyn	0.54	550,0	108/180,0	432/181,44	361,44	83,64	3,61
Dnipropetrovsk	0,34	2433,6	68/113,33	272/114,24	227,57	3.13	2,28
Donetsk	0,34	1107,1	68/113,33	272/114,24	227,57	3,13	2,28
Zhytomyr	0,54	521,8	108/180,0	432/181,44	361,44	63,50	3,61
Transcarpathian	0,40	1043,5	80/133,33	320/134,42	267,73	3,68	2,68
Zaporizhzhia	0,34	536,5	68/113,33	272/114,24	227,57	26,63	2,28
Ivano-Frankivsk	0,54	201,5	108/180,0	432/181,44	361,44	65,77	3,61

Kyiv	0,51	780,4	102/170,0	408/171,36	341,36	4,69	3,42
Kirovohrad	0,40	1401,7	80/133,33	320/134,40	267,73	3,68	2,68
Luhansk	0,40	695,8	80/133,33	320/134,40	267,73	57,05	2,68
Lviv	0,54	587,6	108/180,0	432/181,44	361,44	63,48	3,61
Mykolayiv	0,34	1859,3	68/113,33	272/114,24	227,57	3.13	2,28
Odessa	0,34	2414,6	68/113,33	272/114,24	227,57	3,13	2,28
Poltava	0,40	890,7	80/133,33	320/134,40	267,73	3,68	2,68
Rivne	0,54	415,0	108/180,00	432/181,44	361,44	79,46	3,61
Sumy	0,51	615,7	102/170,00	408/171,36	341,36	82,80	3,41
Ternopil	0,52	849,1	104/173,33	416/174,72	348,05	4,78	3,48
Kharkiv	0,45	1870,0	90/150,00	360/151,2	301,20	4,14	3,01
Kherson	0,34	1395,1	68/113,33	272/114,24	227,57	3,13	2,28
Khmelnytskyi	0,45	954,2	90/150,00	360/151,2	301,20	4,14	3,01
Cherkasy	0,40	817,7	80/133,33	320/134,4	267,73	3,68	2,68
Chernivtsi	0,54	140,6	108/180,00	432/181,44	361,44	84,97	3,61
Chernihiv	0,51	588,4	102/170,00	408/171,36	341,36	69,61	3,41

** the cost indictor represents 1 m^2 of the adobe masonry wall*

Table 4. Distance to the closest region with high yield grain production for regions with low gain yield production (less than 700 thousand tons), assuming no straw contention.

Region of Ukraine	Gross straw harvest, *thousand tons*	Distance to straw production site (km)	Closest region with high yield grain production
Volyn	550,00	168.35	Ternopil
Zhytomyr	521,80	127.81	Vinnytsia
Zaporizhzhia	536,50	85.15	Dnipropetrovsk
Ivano-Frankivsk	201,50	132.38	Ternopil
Luhansk	695,80	155.04	Donetsk
Lviv	587,6	127.77	Ternopil
Rivne	415,0	159.94	Ternopil
Sumy	615,7	176.47	Poltava
Chernivtsi	140,6	171.03	Ternopil
Chernihiv	588,4	148.35	Kyiv

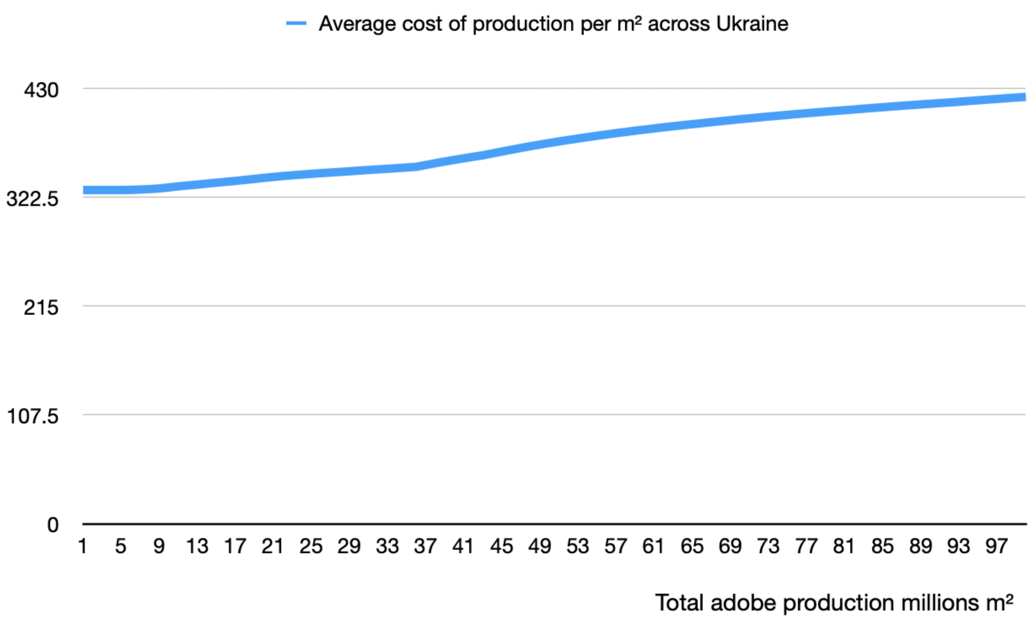

Figure. This graph shows the increase in the average cost of adobe blocks with an increase in their production in Ukraine

To determine which the regions have the highest efficiency for building and using adobe blocks for low-rise residential construction we compute the economic and regional factor N UAH/m^2, N under low straw contention conditions.

Table 5. Rating of regions of Ukraine by the efficiency of using adobe blocks for low-rise residential construction

Zone I: High Efficiency		**Zone II, Medium Efficiency**		**Zone III, Low Efficiency**	
Meaning *N, UAH/m^2*	**Region**	**Meaning *N, UAH/m^2***	**Region**	**Meaning *N, UAH/m^2***	**Region**
1	**2**	**3**	**4**	**5**	**6**
232,98	Donetsk	274,09	Vinnytsia	414,38	Chernihiv
232,98	Dnipropetrovsk	274,09	Kirovohrad	427.57	Sumy
232,98	Odessa	274,09	Poltava	428.53	Lviv
232,98	Mykolaiv	274,09	Cherkasy	428.55	Zhytomyr
232,98	Kherson	274,09	Transcarpathian	430.82	Ivano-Frankivsk
256,48	Zaporizhzhia	308,35	Kharkiv	444.51	Rivne
		308,35	Khmelnytskyi	448.69	Volyn
		327,46	Luhansk	450.02	Chernivtsi
		349,47	Kyiv		
		356,31	Ternopil		

Table 5 shows the rating of the regions of Ukraine in terms of the efficiency of using adobe blocks for low-rise housing construction.

The analysis of the results of the study and the assessment of the obtained indicators establishes that the regions of Ukraine can be conditionally divided into three zones: with high, medium and low efficiency of the use of adobe blocks for low-rise housing construction.

The rating of regions of Ukraine by economic and regional factor N takes into account both the climatic characteristics of the region and the gross harvest of straw for the season, transportation and storage of straw. The high efficiency of using adobe blocks for low-rise adobe construction (Zone I) includes the areas with the lowest value of the indicator N = 232,98-256,48 UAH/m2. The efficiency of using adobe blocks for low-rise residential construction is lowering (almost twice) in the third zone N = 415,9- 439,4 UAH/m2.

We conclude that it's highly advantageous to open enterprises for the industrial production of adobe blocks in zone I, which is characterized by high rates of straw collection (up to 2414.6 thousand tons) per season as well as fairly favorable climatic conditions.

Conclusion

1. We conclude that the annual amount of solar radiation and its duration in hours per year on the territory of Ukraine is sufficient for efficient passive solar structures, providing a sustainable reduction of energy resources needed to heat low-rise residential buildings made of adobe blocks.

2. The use of heliopassive structures in low-rise buildings made of adobe blocks in Ukraine will reduce energy consumption for heating by about 25-30%, and as a secondary effect, will reduce the dependence of households on fluctuations in fuel prices.

3. The paper determines that the indicator of efficiency of the use of adobe blocks N, in the various regions of Ukraine is influenced by:

- climatic conditions of the region, determining the masonry width indicator *(B, m*) for an external wall made of adobe blocks, which affects heat losses and also affects the length of production of adobe blocks (N, days), which are impacted by the time required to dry the blocks (to a normalized moisture content), which in turn depends on the duration of sunlight;
- the amount of gross straw harvest per season, depending on the duration of sunlight;
- the cost of the main construction raw materials (clay, straw), from which adobe blocks are made, their transportation and storage in warehouses with forced ventilation.

4. We developed a new software tool and used it in our analysis:

- to determine the optimal routes for transporting straw imported from neighboring high-yielding regions of Ukraine;
- to analyze the growth of the average cost of adobe blocks with an increase in their production across regions of Ukraine.

5. As a result of the analysis and evaluation of the results of the work, it was determined that the regions of Ukraine can be conditionally divided into three zones with high, medium, and low efficiency of using straw and adobe blocks for energy-efficient low-rise housing construction.

6. All of the regions in the highest efficiency zone for the use of straw adobe blocks are characterized by favorable climatic conditions making walls with low masonry width indicator sufficient. Most of these regions also have high rates of straw production, with the exception of Zaporizhzhia, which requires straw transportation (though over a short distance). We recommend that the enterprises

for the industrial production of adobe blocks are opened in these regions and for the blocks to be used to build local low-rise residential buildings.

REFERENCES:

1. Energy Performance of Buildings Directive (EU/2024/1275) 12 April 2024.- Energy Performance of Buildings Directive (EPBD) / [Electronic resource] // https://ec.europa.eu/commission/presscorner/detail/en/ip_24_1965 / [Eng].
2. The Law of Ukraine "On Energy Efficiency of Buildings" Edition of 15.11.2024 /[Electronic resource]: //https://zakon.rada.gov.ua/laws/show/en/2118-19?lang=uk#Text/ [Ukr].
3. Energy strategy of Ukraine for the period up to 2035. Ministry of Energy and Military Industry of Ukraine. / [Electronic resource]: //http://zakon2.rada.gov.ua/laws/show/n0002120-13/ [Ukr].
4. "The Concept of Implementation of State Policy in the Field of Ensuring Energy Efficiency of Buildings in the Part of Increasing the Number of Buildings with a Close to Zero Energy Consumption Level" Order of the Cabinet of Ministers of January 29, 2020 No. 88-r. / [Electronic resource]: //https://zakon.rada.gov.ua/laws/show/z0284-25#Text/ [Ukr].
5. Atlas of Energy Potential of Renewable Energy Sources of Ukraine: Third Edition, Updated/General. Ed. S.O. Kudry. – Kyiv: Institute of Renewable Energy of the National Academy of Sciences of Ukraine, 2024. – 56 p. /[Electronic resource]: //https://www.ive.org.ua/wp-content/uploads/atlas_2024_publication.pdf/
6. Malyarenko V. A., Gerasimova O. M., Maleev O. I. Construction Heat Physics / Kharkiv: KhNAMG, 2007. – 100 p. [Ukr]
7. Lyubarets O.P., Zaitsev V.O. Design of water heating systems / Kyiv: Vienna-Kyiv, 2010.- 200 p. [Ukr].
8. Shcherbatiuk O.I. Energy-saving systems of heating houses / VNU, Lviv Polytechnic – Lviv, 2003. – 63 p. [Ukr].
9. L.S. Rybchenko, S.V. Savchuk Potential of solar energy climatic resources of solar radiation in Ukraine / Kyiv. Ukrainian Geographical Journal - 2015, No. 4, p.16-23. [Ukr].
10. PE BudPostach-Saman /[Electronic resource]: // https://pp-budpostach.com.ua/ua/a90640-saman.html/ [Ukr].
11. L. S. Rybchenko, S. V. Savchuk Monitoring of Solar Energy Resources of Ukraine / Kyiv, Ukrainian Geographical Journal - 2017, No 19, p.65-71. [Ukr].
12. Statistical collection "Agriculture of Ukraine" for 2022 / Resp. for the issue of O.Prokopenko - State Statistics Service of Ukraine, Kyiv, 2023, 53 p. / [Electronic resource]: //https://ukrstat.gov.ua/druk/publicat/kat_u/2023/zb/09/S_gos_22.pdf
13. Duffie J. A., Solar engineering of thermal processes / J. A. Duffie, W. A. Beckman. – 4th Edition, John Wiley & Sons, Inc., Hoboken, New Jersey, 2013. – 928 p. [Eng].
14. DBN V. 2.6-31:2021 Teplova isolyatsiya ta energoefektivnist' budivel. [Thermal insulation and energy efficiency of buildings] / Ministry of Development of Communities and Territories of Ukraine. 2022. – 23 p. [Ukr].
15. DSTU B V.2.6-189:2013 [Methods of Selection of Thermal Insulation Material for Insulation of Buildings] / Ministry of Regional Development of Ukraine, 2014. – 51 p. [Ukr].
16. DSTU-N B V.1.1-27:2010 [Protection from dangerous geological processes, harmful operational influences, from fire. Building climatology] / Ministry of Regional Development of Ukraine, 2011. – 123 p. [Ukr].