

PAPER • OPEN ACCESS

## Thermal reliability of residential buildings walls and coatings in Ukraine

To cite this article: A Kariuk *et al* 2025 *IOP Conf. Ser.: Earth Environ. Sci.* **1499** 012037

View the [article online](#) for updates and enhancements.

You may also like

- [Assessment of the prospects for the use of treated wastewater for irrigation purposes in the Republic of Crimea](#)  
N E Volkova, N M Ivanyutin and V V Popovich
- [Emissions from stationary pollution sources in the Republic of Crimea in 2013-2018](#)  
V A Tabunshchik, I V Kalinchyk and V O Zhuk
- [The seismic activity analysis in the republic of Crimea](#)  
V V Razumov, A H Adzhiev, N V Razumova et al.



 The Electrochemical Society  
Advancing solid state & electrochemical science & technology

**250**  
ECS MEETING CELEBRATION

*Step into the  
Spotlight*

**SUBMIT YOUR  
ABSTRACT**

**250th ECS Meeting**  
**October 25–29, 2026**  
**Calgary, Canada**  
*BMO Center*

*Submission deadline:*  
**March 27, 2026**

# Thermal reliability of residential buildings walls and coatings in Ukraine

A Kariuk<sup>1</sup>, V Ilchenko<sup>1</sup> and R Mishchenko<sup>1\*</sup>

<sup>1</sup> National University «Yuri Kondratyuk Poltava Polytechnic», Poltava, Ukraine

\*E-mail: ab.Mishchenko\_RA@nupp.edu.ua

**Abstract.** The article analyzes changes in the level of thermal reliability of residential buildings walls and coatings in Ukraine. Numerical indicator of thermal reliability is the probable duration of thermal failure state according to the comfort criterion, which occurs when the permissible temperature difference between internal air and internal surface of the building enclosure is exceeded.

The research was carried out according to the methodology published in the author's previous works, which allows determining the probable duration of thermal failure state, taking into account the statistical characteristics of the atmospheric air temperature in each of the administrative regions of Ukraine. It has been established that within the territory of Ukraine, probable duration of walls thermal failures varies from 7 to 12 minutes per year, and those of coatings - from 153 to 221 minutes per year. The Autonomous Republic of Crimea and the Southern Coast of Crimea with a warmer climate are characterized by a significantly shorter duration of thermal failures. The analysis of obtained values of thermal failures probable duration indicates an uneven level of thermal reliability of residential buildings walls and combined coatings in Ukraine.

For a more accurate equalization of thermal reliability indicators across the territory, it is advisable to clarify the division of Ukraine into temperature zones. For the northeastern regions, it is recommended to slightly increase, and for the Autonomous Republic of Crimea and the Southern Coast of Crimea, to reduce the minimum permissible values of walls and coatings heat transfer resistance.

## 1. Introduction and major challenges

To ensure a sufficient level of building envelopes thermal reliability, Building Code B.2.6-31:2021 [1] sets the minimum required values of heat transfer resistance for two temperature zones of Ukraine. Besides, the value of difference between the temperature of internal air and the temperature of internal surface of the building envelope is limited, which can cause discomfort from being next to enclosures. The random nature of all the values affecting this temperature difference makes it necessary to use probabilistic methods to assess the level of thermal reliability according to the comfort criterion. As a practically understandable, mathematically and physically justified objective indicator of thermal reliability, the research [2] suggests to use the probable duration of the thermal failure state according to the comfort criterion, which occurs when the permissible value of the above temperature difference is exceeded, and methodology for determining this indicator is developed.



A considerable number of studies have been devoted to the analysis of building envelopes thermal characteristics, in particular, articles [2, 3, 4]. Attention has been paid to the selection of thermal characteristics optimal values [5, 6] as well as to improvement of building envelopes aimed at increase in their thermal reliability [7, 8, 18, 19]. The design standards of Ukraine [1] suggest division of the territory into temperature zones with the corresponding values of the calculated parameters of air temperature and the minimum required heat transfer resistance of the building envelope. This approach is to ensure thermal reliability indicators independence from the geographic area. Real quality of thermal reliability regulation level of building envelope structures in Building Code [2] can be assessed by analyzing the results of territorial variability of thermal failures of walls and coatings probable duration.

To determine probable duration of thermal failures according to the methodology [2], it is necessary to represent the enclosure heat transfer resistance and the temperature of the internal air in the form of random variables with a normal distribution law, and the temperature of atmospheric air in the form of a sequence of 12 normally distributed values for each of the months of the year.

Dependencies obtained from the results of experimental tests [9] for the approximate determination of statistical characteristics of the walls heat transfer resistance of typical structures through its calculated value are given in [2]. It was found that mathematical expectation of the heat transfer resistance is approximately 5% higher than its calculated value, and coefficient of variation can be considered close to 0.06.

Statistical characteristics of the indoor air temperature in residential premises were obtained from the measurements conducted in several apartments during the heating season and are given in [10]. It has been established that under manual control of the heat carrier temperature in an autonomous heating system, mathematical expectation of the internal air temperature is 20...24°C, and the standard can be considered equal to 0.6°C.

A probabilistic representation of air temperature in the form of random processes or monthly sequences of random variables was performed in [11, 12], which also provides statistical characteristics of atmospheric air temperature for more than 400 observation points in Ukraine. On the basis of these data, the authors of [13] used the methodology of [14] to perform administrative-territorial zoning of Ukraine according to the statistical characteristics of atmospheric air temperature. For 26 regions of Ukraine (24 oblasts, the Autonomous Republic of Crimea and the Southern Coast of Crimea), the values of mathematical expectation and the air temperature standard for each month of the year were established, which can be used to assess the probable duration of the thermal failures state according to the comfort criterion in these regions of Ukraine.

## **2. Aim and research tasks**

The purpose of this study is to estimate the probable duration of thermal failures of walls and combined coatings of residential buildings in different regions of Ukraine, analyze their territorial variability, and draw conclusions about the need to adjust the minimum required values of heat transfer resistance established in the Ukrainian design standards.

Analysis of the level of thermal reliability of the residential buildings enclosure was performed according to the methodology [2], taking into account the following prerequisites:

- walls and combined coatings, thermal characteristics of which meet the requirements of the State Building Standards of Ukraine [1] are considered;

- the building enclosure is used in the climatic conditions of all administrative regions of Ukraine, the Autonomous Republic of Crimea and the Southern Coast of Crimea with warmer climate;
- the criterion of thermal failure is excess of permissible difference between the internal air temperature in the room and the inner surface temperature of the enclosure established by the norms [1], which is called the comfort criterion in [2];
- the thermal reliability indicator is the probable annual duration of thermal failure according to the comfort criterion.
- the probable duration of thermal failure according to the comfort criterion is estimated according to the methodology developed in [2] and summarized below. For each of the months of the heating period with an average outside air temperature of less than +8°C, mathematical expectation and the standard temperature of internal wall surface are calculated using the formulas from [2]:

$$M_w = \frac{1}{M_R \cdot \alpha_{in}} [M_{in} (M_R \cdot \alpha_{in} - 1) + M_{out}], \quad (1)$$

$$S_w = \frac{1}{M_R \cdot \alpha_{in}} \sqrt{S_{out}^2 + (M_{in} \cdot \alpha_{in} - 1)^2 S_{in}^2 + \frac{(1 - M_R \cdot \alpha_{in})^2}{M_R^2} \cdot S_R^2}, \quad (2)$$

Where  $M_{out}$ ,  $S_{out}$  represent mathematical expectation and standard of outdoor air temperature for the selected region according to [13];

$M_{in}$  is mathematical expectation of the indoor air temperature equal to the calculated value according to [1];

$S_{in}$  is the indoor air temperature standard according to [2, 10];

$\alpha_{in}$  is heat transfer coefficient of the inner surface of the wall or coating;

$M_R$ ,  $S_R$  represent mathematical expectation and standard of heat transfer resistance of a wall or coating, calculated according to the method [2].

Mathematical expectation and standard of the temperature difference between the internal air and the internal surface of the wall are equal to:

$$M_{\Delta} = M_{in} - M_w, \quad S_{\Delta} = \sqrt{S_{in}^2 + S_w^2}, \quad (3)$$

where  $M_w$ ,  $S_w$  are statistical characteristics of the inner surface of the wall temperature (1), (2).

Characteristics (3) make it possible to calculate the duration of the thermal failure state  $Q_j$  in minutes for each  $j$ -th month of the heating period, the total duration of the thermal failure state  $Q$  over the year, and the relative duration of the thermal failure state  $Q_{rel}$  using the formulas from [2]:

$$Q_j = 43920 [1 - F(\Delta_{max})], \quad Q = \sum_j Q_j, \quad Q_{rel} = Q/525600 \quad (4)$$

where  $F(\Delta_{max})$  is a function of the normal distribution of the temperature difference  $\Delta$  with numerical characteristics (3);

$\Delta_{max}$  is the maximum permissible temperature difference between the internal air and the internal surface of the building enclosure of a residential building according to [1];

43920 and 525600 are the lengths of a month and a year in minutes.

Annual duration of the thermal failure state  $Q$  is a practically understandable numerical indicator by which it is possible to compare building enclosures of different types used in various climatic conditions. Relative duration of the thermal failure state  $Q_{rel}$  can be considered an approximate estimate of thermal failure probability during the year.

### 3. Research methodology

The walls and residential buildings combined coatings of a complex design that meets the standards requirements are analyzed [15, 16]. The walls bearing part is made of brick or cellular concrete, while facade insulation is made of mineral wool or other similar material. Combined coatings of residential buildings consist of a load-bearing reinforced concrete slab, insulation made of mineral wool boards and waterproofing based on bituminous or synthetic roll materials. External protective layers and interior finishes do not have significant resistance to heat transfer, which makes it possible not to take them into account in thermal engineering calculations.

Walls and coatings thermal characteristics are shown in Table 1. Calculated values of the heat transfer resistance  $R_0$  are assumed to be equal to the minimum required values established by the standards [1] for both temperature zones of Ukraine. Mathematical expectation MR and the standard SR of the heat transfer resistance of enclosures are determined by the approximate dependencies given in [2].

According to [17], the heat transfer coefficient of the wall inner surface in formulas (1) and (2) is assumed to be  $\alpha_{in} = 8.7 \text{ W}/(\text{m}^2 \text{ K})$ , and that of the flat surface  $\alpha_{in} = 10.0 \text{ W}/(\text{m}^2 \text{ K})$ .

Mathematical expectation of the indoor air temperature is equal to the design value for residential premises established by the standards [1]  $M_{in} = +20^\circ\text{C}$ . The standard for indoor air temperature based on the results of experimental studies [10] is  $S_{oin} = 0.6^\circ\text{C}$ .

Mathematical expectations  $M_{out}$  and standards  $S_{out}$  of the outdoor air temperature in each of the months of the year are taken from [13]. In this study, according to [12], for 414 plain observation points of Ukraine located at altitudes up to 500 m above sea level, the weighted average values of  $M_{out}$  and  $S_{out}$  for each of the 24 administrative regions of Ukraine, the steppe zone of the Autonomous Republic of Crimea, and separately for the Southern Coast of Crimea were obtained using the method of administrative-territorial zoning [14]. Thus, annual variation of atmospheric air temperature in 26 regions of Ukraine is presented in the form of sequences of 12 random variables with a normal distribution law, which are necessary for assessing the building enclosures thermal reliability according to the method [2].

### 4. Results

Indicators of thermal reliability of walls and coatings for 26 regions of Ukraine were calculated using formulas (1)...(4), taking into account the above initial data and statistical characteristics of the atmospheric air temperature from [13]. The results of the calculations are given in Table 2, which contains the probable annual duration of thermal failures according to the comfort criterion  $Q$  (minutes per year) and the relative duration of thermal failures  $Q_{rel}$  of walls and coatings. Based on the available data, the smallest, largest and average values of the thermal failures duration for the first and second temperature zones of Ukraine (excluding the Southern coast of Crimea) were also determined.

Table 2 shows that, with the exception of the Southern Coast of Crimea, the smallest, largest and average values of the walls thermal failures duration in the first and second temperature zones of Ukraine are quite close. Probable duration of coatings thermal failures obtained in the first temperature zone was on average by 12% longer than in the second one. Probable duration of walls and coatings thermal failures in the territory of the Autonomous Republic of Crimea and the Southern Coast of Crimea is much shorter due to the warmer subtropical climate.

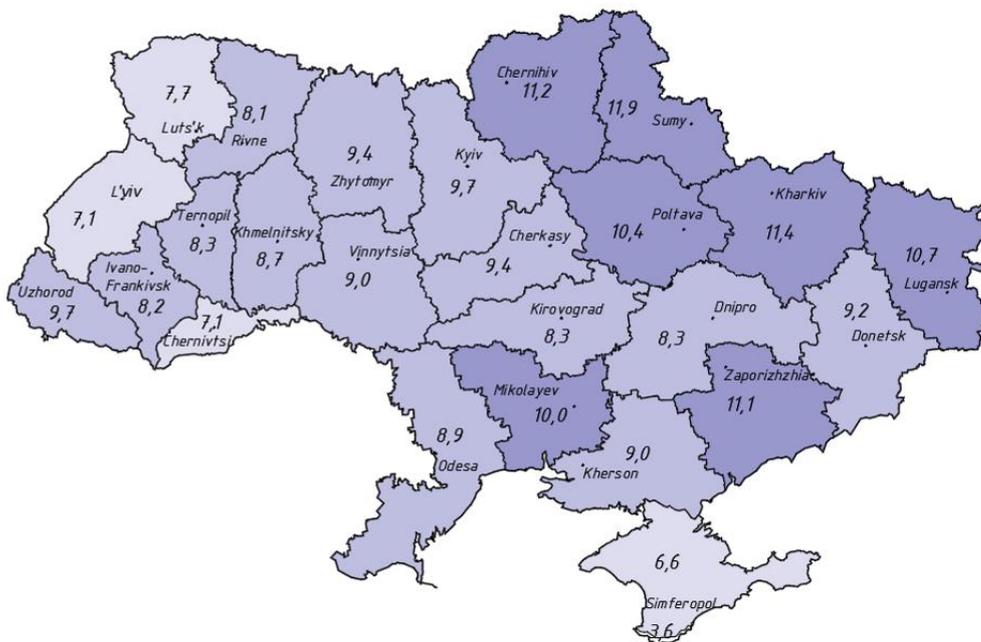
**Table 1.** Characteristics of heat transfer resistance,  $m^2 \times K/W$ 

Enclosing structures	R0	MR	SR
Walls in the first temperature zone	4.0	4.20	0.252
Walls in the second temperature zone	3.5	3.68	0.221
Coatings in the first temperature zone	7.0	7.36	0.441
Coatings in the second temperature zone	6.0	6.30	0.378

**Table 2.** Probable duration of roofs and walls thermal failures

The first temperature zone	Walls		Roofs	
	Q min./year $R_0 = 4.0 m^2 \times K/W$	$Q_{rel}$	Q min./year $R_0 = 7.0 m^2 \times K/W$	$Q_{rel}$
Vinnitsia	9.0	1.71E-05	199	3.79E-04
Lutsk	7.7	1.46E-05	189	3.60E-04
Dnipro	8.3	1.58E-05	163	3.10E-04
Donetsk	9.2	1.75E-05	169	3.22E-04
Zhytomyr	9.4	1.78E-05	203	3.86E-04
Ivano-Frankivsk	8.2	1.55E-05	193	3.67E-04
Kyiv	9.7	1.84E-05	205	3.90E-04
Kirovohrad	8.3	1.58E-05	163	3.10E-04
Luhansk	10.7	2.03E-05	195	3.71E-04
Lviv	7.1	1.36E-05	169	3.22E-04
Poltava	10.4	1.97E-05	209	3.98E-04
Rivne	8.1	1.54E-05	193	3.67E-04
Sumy	11.9	2.27E-05	221	4.20E-04
Ternopil	8.3	1.58E-05	194	3.69E-04
Kharkiv	11.4	2.16E-05	216	4.11E-04
Khmelnyskyi	8.7	1.65E-05	197	3.75E-04
Cherkasy	9.4	1.79E-05	202	3.84E-04
Chernivtsi	7.1	1.35E-05	153	2.92E-04
Chernihiv	11.2	2.12E-05	216	4.11E-04
Minimum	7.1	1.35E-05	153	2.92E-04
Maximum	11.9	2.27E-05	221	4.20E-04
Average	9.1	1.74E-05	192	3.66E-04
The second temperature zone	$R_0 = 3.5 m^2 \times K/W$		$R_0 = 6/0 m^2 \times K/W$	
Right bank of Crimea	3.6	6.80E-06	106	2.01E-04
Uzhhorod	9.7	1.85E-05	175	3.33E-04
Zaporizhzhya	11.1	2.11E-05	186	3.53E-04
Autonomous Republic of Crimea	6.6	1.25E-05	152	2.89E-04
Mykolaiv	10.0	1.90E-05	178	3.38E-04
Odesa	8.9	1.69E-05	170	3.23E-04
Kherson	9.0	1.71E-05	171	3.25E-04
Minimum	6.6	1.25E-05	152	2.89E-04
Maximum	11.1	2.11E-05	186	3.53E-04
Average	9.2	1.75E-05	172	3.27E-04

The data in Table 2 are visualized in Figures 1 and 2, which enable analyzing trends in the territorial changes in the level of thermal reliability of residential buildings walls and coatings in different regions of Ukraine.



**Figure 1.** Annual duration of residential building walls thermal failures in Ukraine.



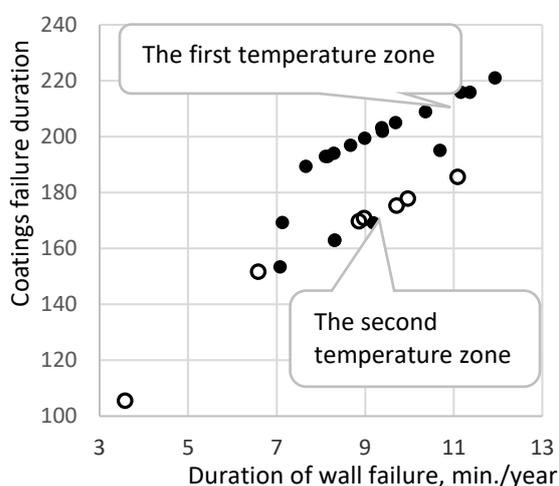
**Figure 2.** Annual duration of thermal failures of residential building coatings in Ukraine.

For all 26 regions of Ukraine, probable duration of thermal failures of coatings was obtained to be 17...30 times longer than for walls. This is explained by the different values of the permissible temperature differences  $\Delta_{max}$  in formula (4): 4°C for walls and 3°C for coatings. Therefore, probable duration of thermal failure according to the comfort criterion (4) can only be used to compare the level of thermal reliability of structures with the same  $\Delta_{max}$  at different values of other parameters.

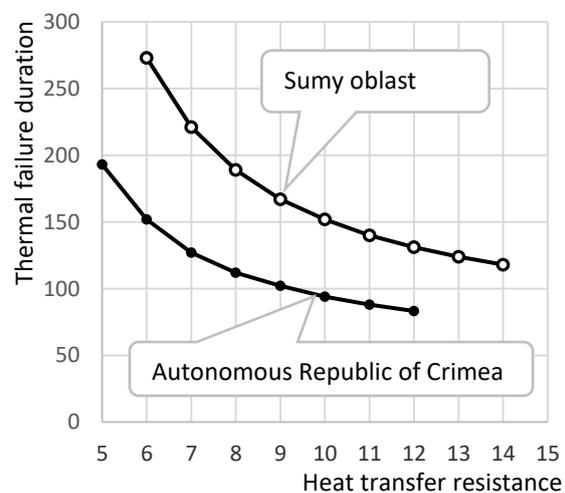
The analysis of the map in Figure 1 revealed patterns of territorial changes in the duration of thermal failures within the first temperature zone. The duration of thermal failures for the northeastern regions (Chernihiv, Sumy, Kharkiv, Luhansk, Poltava), as well as Mykolaiv and Zaporizhzhia regions, which belong to the second temperature zone according to [1], was significantly longer than for other regions of Ukraine. This indicates the expediency of allocating these regions to additional temperature zones with slightly higher minimum permissible values of wall heat transfer resistance. At the same time, in order to equalize the thermal reliability of walls throughout Ukraine, the minimum permissible value of the walls heat transfer resistance in the Autonomous Republic of Crimea and especially on the Southern Coast of Crimea should be reduced.

The schematic map in Figure 2 shows the changes in probable duration of the coatings thermal failure state (in minutes per year) across Ukraine. The map shows a rather systematic increase in the duration of thermal failure from southwest to northeast. Similar to walls, the shortest duration of thermal failure is observed in Crimea and especially on the Southern coast of Crimea.

Comparison of coatings and walls thermal failures duration is made according to Table 2. The table shows that duration of coatings thermal failures is 17...30 times longer than that of walls.



**Figure 3.** Relationship between the walls and roofs thermal failures duration.



**Figure 4.** Dependence of the failure time on the roof heat transfer resistance

The relationship between thermal failures duration of walls and coatings is shown in Figure 3. It is divided into two straight-line dependencies formed by the data of the first (dark markers) and mainly the second (light markers) temperature zone. The revealed difference in data for the first and second temperature zones confirms the expediency of adjusting the minimum required

heat transfer resistance of walls and coatings established in DBN [1] for the two temperature zones of Ukraine.

Table 2 shows that the duration of the state of coatings thermal failure can reach 221 minutes per year, i.e., almost 4 hours during the year. Since such duration of the thermal failure state of coatings is quite long, the possibility of reducing it by increasing the heat transfer resistance is analyzed. Figure 4 shows changes in the thermal failure state duration from the coating heat transfer resistance for the conditions of the Crimea and Sumy region, which have the highest (except for the Southern coast of Crimea) and the lowest level of roofs thermal reliability. The figure shows that even a twofold increase in the heat transfer resistance compared to the requirements of Building Code [1] does not provide a fundamental reduction in the thermal failure state duration. Obviously, the reason for the lower level of coatings thermal reliability compared to walls is the overly stringent requirement for the maximum permissible temperature difference between the internal air and the enclosure internal surface, equal to  $\Delta_{\max} = 3^{\circ}\text{C}$  instead of  $\Delta_{\max} = 4^{\circ}\text{C}$  for walls. To ensure the uniformity of roofs and walls throughout Ukraine, it is necessary to adjust both the minimum permissible values of the enclosures heat transfer resistance and permissible values of the temperature difference  $\Delta_{\max}$  between the internal air and the internal surface of the enclosure in the standards [1].

#### 4. Conclusions

1. The use of the thermal failures probable duration according to the comfort criterion, calculated taking into account the statistical characteristics of atmospheric air temperature generalized for the regions of Ukraine, made it possible to analyze the territorial variability of the level of thermal reliability of residential buildings walls and coatings.

2. It has been established that within the first temperature zone of Ukraine according to Building Code B.2.6-31:2021 "Thermal insulation of buildings", the probable duration of thermal failures of walls varies from 7 to 12 minutes per year. The probable duration of walls thermal failures in the northeastern regions (Chernihiv, Sumy, Kharkiv, Luhansk, Poltava), as well as in Zaporizhzhia and Mykolaiv oblasts is significantly longer, and in Crimea it is significantly shorter than in other territories of Ukraine.

3. Probable duration of combined coatings thermal failures, heat transfer resistance of which meets the requirements of Building Code B.2.6-31:2021, increases quite systematically from southwest to northeast, varying within 153...221 minutes/year. The duration of coatings thermal failure on the territory of the Southern coast of Crimea is much shorter.

4. To more accurately equalize the walls thermal reliability in different regions of Ukraine, it is advisable to allocate the northeastern regions of Ukraine to a separate temperature zone with a higher resistance to heat transfer of enclosures. Reduced requirements for the heat transfer resistance of walls can be set for the Autonomous Republic of Crimea and the Southern Coast of Crimea.

5. The probable duration of combined coatings thermal failures is 17...30 times longer than the duration of thermal failures of walls. It is practically impossible to ensure equal reliability of building enclosures by increasing the thickness of thermal insulation and, accordingly, the heat transfer resistance of combined coatings, which indicates the expediency of adjusting the buildings thermal protection standards.

## References

- [1] DBN B.2.6-31: 2021: Thermal insulation and energy efficiency of buildings (Kyiv Ministry of Construction of Ukraine 2022) (in Ukrainian)
- [2] Kariuk A, Pashynskiy V, Pashynskiy M and Mammadova F 2022 Methods of Probabilistic Assessment of Building Enclosing Structures Thermal Reliability *Lecture Notes in Civil Engineering* **181** pp 179-189 ([https://doi.org/10.1007/978-3-030-85043-2\\_18](https://doi.org/10.1007/978-3-030-85043-2_18))
- [3] Košir M, Pajek L, Hudobivnik B, Dovjak M, Igljič N, Bozicek D and Kunič R 2017 Non-Stationary Thermal Performance Evaluation of External Façade Walls Under Central European Summer Conditions. *ISES Conference Proceedings*, pp. 1-10 (<https://doi.org/10.18086/swc.2017.15.03>)
- [4] Ahmed Kaiser & Carlier Margaux & Feldmann Christian & Kurnitski Jarek 2018 A New Method for Contrasting Energy Performance and Near-Zero Energy Building Requirements in Different Climates and Countries *Energies, MDPI, Open Access Journal* **11(6)** pp 1-22 (<https://doi.org/10.3390/en11061334>)
- [5] Scartezzini Jean-Louis & DUMAN Öykü & Koca Aliihsan & Acet Ruşen & ÇETIN Mevlüt & Gemici Zafer 2015 A study on optimum insulation thickness in walls and energy savings based on degree day approach for 3 different demo-sites in Europe *Future Buildings and Districts Sustainability from Nano to Urban Scale* pp. 155-160 (<https://doi.org/10.5075/epfl-cisbat2015-155-160>)
- [6] Kaynakli Ömer & Kaynakli Faruk 2016 Determination of Optimum Thermal Insulation Thicknesses For External Walls Considering The Heating, Cooling And Annual Energy Requirements. *Uludağ University Journal of The Faculty of Engineering* **21** pp 227-241 (<https://doi.org/10.17482/uujfe.27323>)
- [7] Kariuk A, Rubel V, Pashynskiy V and Dzhyrma S 2020 Improvement of Residential Buildings Walls Operation Thermal Mode *Proceedings of the 2nd International Conference on Building Innovations. ICBI 2019. Lecture Notes in Civil Engineering* **73** 75-81 ([https://doi.org/10.1007/978-3-030-42939-3\\_9](https://doi.org/10.1007/978-3-030-42939-3_9))
- [8] Pashynskiy M, Dzhyrma S, Pashynskiy V and Nastoyashchiy, V. 2020 Providing the thermal reliability of window junctions during the thermal modernization of civil buildings, *Electronic Journal of the Faculty of Civil Engineering Osijek-e-GFOS* **21** pp 45-54 (<https://doi.org/10.13167/2020.21.4>)
- [9] Semko, O., Filonenko, O., Yurin, O., Sankov, P., Mahas, N. (2023). Analysis of Influence of Metal Elements of Window and Door Openings in Brick Walls on the Temperature of the Interior Plain of a Wall at the Place of Their Installation. *Proceedings of the 4th International Conference on Building Innovations. ICBI 2022. Lecture Notes in Civil Engineering*, vol **299**. Springer, Cham. [https://doi.org/10.1007/978-3-031-17385-1\\_25](https://doi.org/10.1007/978-3-031-17385-1_25)
- [10] Pashynskiy V, Pashynskiy M, Nastoyashchiy V and Skrynnyk I 2023 Statistical characteristics of wall temperature for assessing thermal reliability and energy efficiency of residential buildings. *Modern engineering and innovative technologies issue 26 part 2 April 2023* pp 19-25 (<https://doi.org/10.30890/2567-5273> (date of access: 26.01.2024))
- [11] Filonenko, O., Farenjuk, G., Semko, O., Mahas, N. (2022). Research of Methods of Calculation of Thermal Characteristics of Enclosing Designs in Summer Conditions of Operation. In: Onyshchenko, V., Mammadova, G., Sivitska, S., Gasimov, A. (eds) *Proceedings of the 3rd International Conference on Building Innovations. ICBI 2020. Lecture Notes in Civil Engineering*, vol **181**. Springer, Cham. [https://doi.org/10.1007/978-3-030-85043-2\\_12](https://doi.org/10.1007/978-3-030-85043-2_12)
- [12] Pashynskiy V A, Pushkar N V and Kariuk A M 2012 *Temperature effects on the enclosing structures of buildings (monograph)* (Odessa) 180 p
- [13] Pashynskiy, Mykola & Pashynskiy, Victor & Tykhyi, Andrii & Karpushyn, Serhii. (2023). Long-term forecasting of thermal and humidity actions on buildings. *Advances in Civil and Architectural Engineering*. **14**. 1-9. <https://doi.org/10.13167/2023.26.1>
- [14] Pashynskiy V 2016 Metodyka administratyvno-terytorialnoho raionuvannia klimatychnykh navantazhen na budivelni konstruktsii *Resursoekonomni materialy, konstruktsii, budivli ta sporudy* **32** pp 387-393
- [15] DBN H B.2.6-33:2018 External wall structures with facade thermal insulation. Design requirements (Kyiv) (in Ukrainian)
- [16] DBN B.2.6-220:2017 Covering buildings and structures (Kyiv) (in Ukrainian)
- [17] DSTU 9191:2022 Thermal insulation of buildings. Method of selecting thermal insulation material for building insulation (Kyiv) (in Ukrainian)
- [18] Waleed A. Al-Awsh, Naef A.A. Qasem, Omar S. Baghabra Al-Amoudi, Mohammed A. Al-Osta, Experimental and numerical investigation on innovative masonry walls for industrial and residential buildings, *Applied Energy*, Volume **276**, 2020, 115496, ISSN 0306-2619, <https://doi.org/10.1016/j.apenergy.2020.115496>.
- [19] Naef A.A. Qasem, Ahmed S. Al-Tamimi, Vivek Bindiganavile, Thermal energy storage and losses in various types of masonry concrete walls, *Journal of Energy Storage*, Volume **67**, 2023, 107555, ISSN 2352-152X, <https://doi.org/10.1016/j.est.2023.107555>.