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DYNAMIC PERFORMANCE ASSESSMENT OF MULTILAYERED WALL ASSEMBLIES

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This paper introduces an approach to assessing the dynamic performance of multilayered building envelopes, focusing on physically measurable thermal performance metrics. Based on EN ISO 13786:2023, the study considers thermal transmittance (U-value), internal areal heat capacity (k_1), and decrement factor (f) as thermal performance parameters, and wall mass as an additional objective indicator. Five wall assemblies common in the Ukrainian market - hempcrete, AAC + Rockwool, Porotherm brickwork + Rockwool, wood-chip cement-bonded blocks (Woodcrete) and ICF systems were evaluated through numerical modelling and comparative analysis. To eliminate subjectivity in the weighting of criteria, the four physically meaningful parameters are compared to determine the overall assessment. Results indicate that Wall E (ICF) ranks as the dynamically balanced, efficient assembly according to the internal area heat capacity and decrement factor parameters, but it has the maximum mass among other assemblies. Wall B (AAC) demonstrated the highest heat-flux attenuation effect, 0.115, which can lead to summer overheating, while Wall C (hollow brick + insulator) and Wall D (Woodcrete) demonstrated a similar dynamic behaviour with a too-low decrement factor, 0.007. The study highlights the complexity of MCDA in envelope design and provides physically grounded criteria that can support more objective predesign decision-making. Current research revealed that, even though all the walls meet the requirements of the Ukrainian National Building Code, steady-state thermal transmittance coefficient (U-value) can be considered only in the early stages of decision-making as the primary determinant of envelope efficiency; however, this parameter alone fails to accurately reflect the dynamic thermal behaviour of constructions and their inertia-related performance.

Keywords: *Dynamic thermal performance, Multilayered assembly, Envelopes, Energy efficiency, Physical parameters.*

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Introduction

Buildings account for a substantial share of global energy consumption, with the building envelope serving as the primary interface governing heat exchange between indoor and outdoor environments. In this context, wall assemblies play a decisive role not only in reducing steady-state heat losses but also in moderating transient thermal loads caused by diurnal and seasonal climatic variations 0 [1]. The increasing need for low-energy, climate-resilient buildings has therefore shifted attention from purely steady-state indicators to the dynamic thermal behaviour of envelope systems [2], especially due to the possible decrease in energy consumption by employing adequate thermal mass materials to 7-22% [3].

Traditionally, the thermal quality of wall systems has been evaluated using the steady-state thermal transmittance coefficient (U-value). However, numerous studies have shown that this parameter alone does not adequately reflect the actual thermal response of multilayered, massive wall assemblies under cyclic boundary conditions [4], [5]. In particular, the capacity of the envelope to store, delay, and attenuate heat flux — commonly described by the decrement factor (*f*), time lag, thermal admittance, and internal areal heat capacity (k_1) — becomes essential for accurately assessing building performance under real operating conditions [4], [6].

The significance of thermal mass has been widely recognised in building physics [7], [8]. Proper application of thermally massive materials can reduce heating and cooling loads by shifting peak heat fluxes away from occupied hours and improving the interaction between the building and passive climatic strategies such as night cooling and solar heat storage [3], [7], [8], [13], [16]. Earlier investigations demonstrated that thermal mass effects are strongly dependent on material arrangement, insulation position, climatic conditions, and daily temperature oscillation characteristics [1], [4], [5], [7], [8].

Particular attention has been given to multilayered and composite envelopes, where the interaction between layers with significantly different thermal diffusivities and heat capacities leads to complex dynamic responses. Previous works by Kosny, Kossecka [1], [2] and other authors [7], [8], [9], [10], [11], established the theoretical basis for evaluating the dynamic thermal performance of such systems using equivalent wall theory, response factors, and whole-building simulation approaches. These studies confirmed that simplified steady-state representations may significantly underestimate or overestimate the real performance of complex wall systems, especially in assemblies containing concrete cores, masonry blocks, and thermally insulating layers [7].

Despite considerable progress in thermal mass assessment, the problem of objective benchmarking of modern energy-efficient multilayered wall assemblies remains insufficiently addressed [4]. Contemporary wall technologies — including hempcrete monoliths, autoclaved aerated concrete with external insulation, hollow clay block systems, woodcrete blocks, and insulated concrete forms — differ substantially in both their dynamic thermal response and embodied environmental burden. Existing evaluation methods often rely on subjective weighting or focus solely on isolated parameters, which complicates rational decision-making during the pre-design stage.

However, a comparative deficiency remains in the literature regarding integral metrics that connect physical and mechanical properties as an actionable selection tool for design optimisation. The U-value (W/m²K), internal area heat capacity (k_1), kJ/m²K and the decrement factor (*f*) reflect thermal parameters that are primary influencers of envelope winter and summer behaviour [4], but there is limited methodological convergence between them. Some attempts to bridge this include thermal mass assessments [7], [8] or dynamic-to-static performance coefficients [13]; however, such indicators have yet to be standardised or validated across material groups.

The present study aims to address this gap by proposing a physically based benchmarking framework for the dynamic performance assessment of energy-efficient multilayered wall assemblies. The analysis combines standardised dynamic thermal indicators, based on dynamic thermal performance standards outlined in Ukraine National Standard DSTU EN ISO 13786:2023 [16], to facilitate the decision-making process during the early stages of building design, easily calculable physical criteria that relate thermal performance to mass were chosen, including thermal transmittance (U-value), W/m²K, mass (*m*, kg/m²), decrement factor (*f*) and internal area heat capacity (k_1), kJ/m²K.

Purpose and tasks of research

The current research aims to formulate additional criteria for early-stage multilayered wall assembly design assessment of energy-efficiency potential, based exclusively on physical parameters of envelope materials and taking into account dynamic thermal characteristics as well as embodied energy as the LCA component, which can provide a more objective comparison of different multilayered wall assemblies in terms of their thermophysical and physical-mechanical parameters. This direction is particularly relevant given the rising need for buildings that harmonise material rationality, climate adaptability, and lifecycle sustainability.

To achieve this goal, the following tasks should be solved:

a) a list of multilayered wall assemblies for the medium cost segment of residential buildings, based on the conducted data review, should be revealed.

b) the key physical and thermophysical parameters for the wall dynamic performance should be benchmarked.

Materials and methods

The physical criteria that could easily be calculated in the early-stage multi-layered assembly design of the construction, such as thermal transmittance (U-value), W/m^{2}K, mass (m, kg/m^2), and internal area heat capacity (k_1), kJ/m^{2}K, as a dynamic thermal performance parameter under DSTU EN ISO 13786:2023 [16] for the wall assembly, were taken.

The numerical assessment of dynamic thermal performance efficiency parameters, such as thermal transmittance (U-value), W/m^{2}K, the decrement factor (*f*) and internal area heat capacity (k_1) kJ/m^{2}K was performed in the HTflux [17] – freely downloadable Excel-based calculator spreadsheets.

Main part

For numerical simulation setup of the dynamic thermal performance efficiency parameters, five types of multilayered wall assemblies (see detailed cross-sections in Figure 1), were chosen as popular assemblies in the Ukrainian construction market, namely: Wall A (Hempcrete) as energy efficient and eco-friendly type, Wall B (Aerated autoclaved concrete (AAC) D300 + Rockwool as insulation material) as the affordable cost-efficient type of energy efficient solution; Wall C (Hollow brickwork masonry (Porotherm 38) + Rockwool as insulation material) as traditional reliable ceramic brickwork masonry with energy efficient porous brick, Wall D (Wood-chip cement bonded block) as energy efficient and “retrofitted” technology and Wall E (wood-chip cement bonded block, as one of the promising type of Insulated concrete formwork (ICF), which gained a significant traction in EU, North American and Australian construction market and is commercially distributed under trademarks as ISOTEX [18], [19], Fixolite [20], Isolabloc [21], Isospan [22], Fasswall [23], Nexcem [24], Durisol [25] etc.) as well-known wall construction technology in European, North American and Australian construction markets and new construction technology competitor at the Ukrainian one. In Figures 1-5, there are photos from real construction sites showing the investigated assemblies, and in Figure 6, a detailed cross-section drawing.

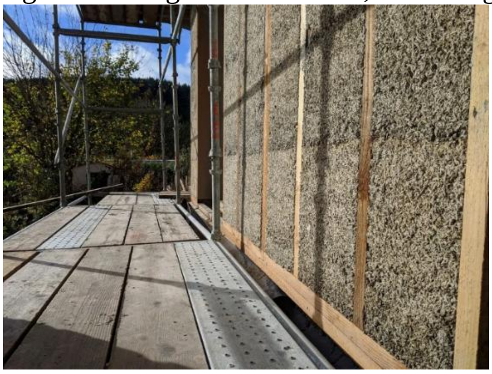

Figure 1 – Hempcrete wall performed by the tamping method
Source: [26]

Figure 2 – AAC façade insulated with stone-wool wall insulator
Source: [27]

Figure 3 – Hollow ceramic blocks wall
Source: [28]

Figure 4 – Wood-chip cement-bonded blocks wall
Source: [29]

Figure 5 – Layering of ISOTEX - ICF wood-chip cement-bonded blocks
Source: [30], [31]

The dynamic thermal characteristics of each multilayered assembly were determined below under DSTU EN ISO 13786:2023 [16] using the following sequence:

1) Definition of thermophysical properties (ρ, c, λ) for each layer;
2) Calculation of penetration depth;
3) Determination of dimensionless thickness;
4) Construction of layer transfer matrices;
5) Assembly of the global transmittance matrix;
6) Extraction of dynamic parameters: internal areal heat capacity (k_1), decrement factor (f).

The calculations were implemented in a spreadsheet environment [17] and verified against values reported in [4], [10], [13], and [30].

Thermal transmittance (U-value) under [31] of the aforementioned multilayered assemblies is calculated as follows in formula (1)

$$\mathrm{U-value} = \frac{1}{R_{si}+\sum_{i=1}^{n}\frac{d_i}{\lambda_i}+R_{se}}, \quad (1)$$

where R_{si}=1/8.7 – interior layer thermal resistance, m^2K/W [33];

R_{se}=1/23 – exterior layer thermal resistance, m^2K/W [33];

d_i, λ_i – the thickness and thermal conductivity coefficient of the *i*-th layer, respectively.

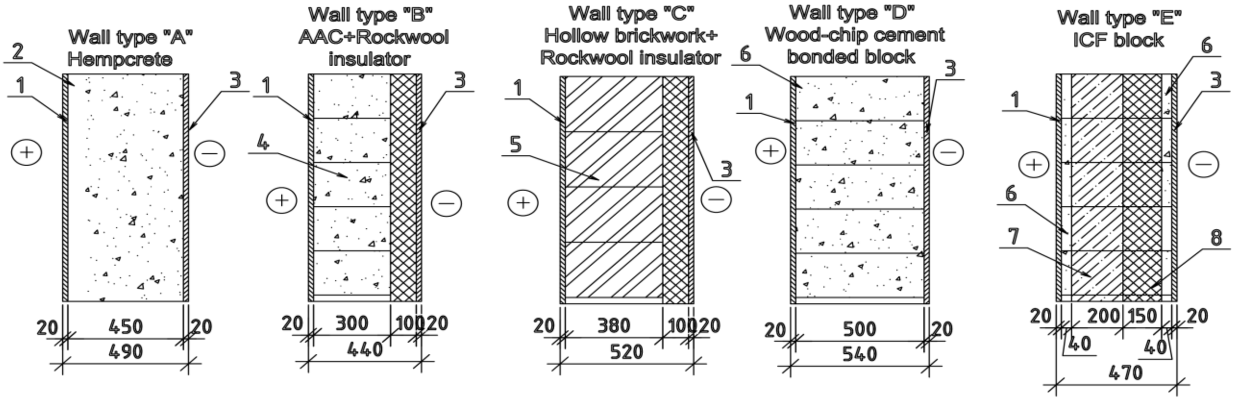

Figure 6 – Cross-sectional scheme of investigated wall assemblies: 1 - internal lime-sand plaster, 2 - hemcrete, 3 - external lime-sand plaster, 4 - aerated autoclaved concrete (AAC), 5 - hollow brickwork, 6 - wood-chip cement bonded block (woodcrete), 7 - reinforced concrete, 8 - BASF Neopor insulator)
Source: drawn by the authors

Penetration depth of the *i*-th layer under [16] is calculated according to the formula (2)

$$\delta_i = \sqrt{\frac{\lambda_i \times T}{\pi \times \rho_i \times c_i}}, \quad (2)$$

where *T*=24hours – oscillation time, considered for envelopes;

ρ_i, c_i – the density and specific heat capacity of the *i*-th layer.

Dimensionless penetration depth under 0 is calculated as represented in the formula (3)

$$\xi = \frac{d_i}{\delta_i}. \quad (3)$$

Thermal transmittance matrix component of each i-th layer under [16] is calculated as follows in formulae (4)-(6)

$$z11_i = z22_i = \cos(\xi_i \times (1i - 1)), \quad (4)$$

where $1i = \sqrt{-1}$.

$$z12i = -\frac{\delta_i}{2\times\lambda_i} \times (-1i - 1) \times \sin(\xi_i \times 1i - \xi_i); \quad (5)$$

$$z21i = -\frac{\lambda_i}{\delta_i} \times (-1i - 1) \times \sin(\xi_i \times 1i - \xi_i) \quad (6)$$

Thus, the transmittance matrix of the i-th layer is defined as [16] and is to be arranged as in formula (7)

$$Z_i = \begin{bmatrix} z11_i & z12_i \\ z21_i & z22_i \end{bmatrix}. \quad (7)$$

In case we have a multilayered envelope, the total transmittance matrix will be the product of the total transmittance matrix Z_{tot} of each *i*-th layer, from the interior to exterior, in terms of envelope cross-section, as it is represented in formula (8) under [16]

$$Z_{tot} = \prod_{i=1}^{k} Z_i, \quad (8)$$

where $k = 1,2,\dots,n$ – number of layers.

The boundary layer thermal transmittance matrix under [16] is calculated as follows in formula (9)

$$Z_{s1} = \begin{bmatrix} 1 & -R_{se} \\ 0 & 1 \end{bmatrix}; \quad (9)$$

$$Z_{s2} = \begin{bmatrix} 1 & -R_{si} \\ 0 & 1 \end{bmatrix}. \quad (10)$$

Construction thermal transmittance matrix of multilayered envelope from environment to environment, according to [16], to be calculated as defined in formula (11)

$$Z_{ee} = Z_{s2} \times Z_{tot} \times Z_{s1} \quad (11)$$

Internal area heat capacity (k_1) and decrement factor (f) under [16] are to be calculated as defined in formulae (12)-(13)

$$k_1 = \left|\frac{Z_{ee_{2,2}}-1}{Z_{ee_{1,2}}}\right| \times \frac{T}{2\times\pi}; \tag{12}$$

$$f = \frac{\left|\frac{Z_{ee_{2,2}}-1}{Z_{ee_{1,2}}}\right|\times\frac{T}{2\times\pi}}{U-value}, \tag{13}$$

where $Z_{ee2,2}$, $Z_{ee1,2}$–elements of the second column of the second row and the second column of the first row of the construction thermal transmittance matrix, respectively.

The initial thermophysical parameters of the assembly materials used in the current numerical experiment (numerator), obtained from the referenced data range (denominator), are aggregated in Table 1.

Table 1

The initial thermophysical parameters of assembly materials

Assembly material	The thermophysical parameters of materials			Data reference
	Specific heat capacity, c (J/kgK)	Density ρ, (kg/m^3)	Thermal conductivity λ, (W/m·K)	
Lime-sand plaster	1000	1500	0.67	[33]
Hempcrete	$\frac{1200}{1000-1600}$	$\frac{450}{200-627}$	$\frac{0.08}{0.05-0.18}$	[34], [35], [36], [37], [38]
Aerated autoclaved concrete (AAC)	100	275	0.09	[33]
Hollow brickwork masonry	1000	745	0.112	[33], [39], [40]
Wood-chip cement-bonded block	$\frac{1400}{1000-1700}$	$\frac{475}{475-587.4}$	$\frac{0.12}{0.1-0.12}$	[18], [19], [20], [21], [22], [23], [24], [25]
Reinforced concrete	1000	2200	1.65	[33], [42], [43]
Neopor insulator	$\frac{1450}{1200-1600}$	$\frac{16}{15-25}$	$\frac{0.031}{0.031-0.032}$	[42]
Stone wool wall insulator	$\frac{1030}{800-1030}$	$\frac{70}{30-200}$	$\frac{0.034}{0.033-0.045}$	[33], [43]

Source: compiled by the authors.

The output influence parameters for all the assemblies are calculated in Table 2.

Table 2

Calculated parameters for researched assemblies

Influence parameter	Wall type "A"	Wall type "B"	Wall type "C"	Wall type "D"	Wall type "E"
U-value, W/m^{2}K	0.17*	0.15	0.15	0.22	0.17
m, kg/m^2	262.50	149.50	350.10	335.00	540.39
k_1, kJ/m^{2}K	39.955	37.369	43.742	43.551	40.073
f	0.013	0.115	0.007	0.007	0.052

Source: compiled by the authors.

*For simplicity, the timber frame input is not taken into consideration;

From the analysis of Table 2, it could be noticed that all the researched assemblies meet the minimum permissible value of the reduced heat transfer resistance of enclosing structures of residential and public buildings, as required for Ukraine $R_{qmin} = 4.0\ \frac{m^2\text{K}}{\text{W}}$ 0, or by a more convenient unit $\text{U}-\text{value} = \frac{1}{R_{qmin}} = 0.25\ \frac{\text{W}}{m^2\text{K}}$ with significant energy efficiency potential (wall B and wall C, respectively, with the same $\text{U}-\text{value} = 0.15\frac{\text{W}}{m^2\text{K}}$. Wall A and Wall E also demonstrate a sufficient level of $\text{U}-\text{value} = 0.17\frac{\text{W}}{m^2\text{K}}$. The last preferable Wall type from the perspective of thermal transmittance is Wall D with $\text{U}-\text{value} = 0.22\frac{\text{W}}{m^2\text{K}}$.

From the dynamic performance characteristics, such as (k_1) and (f), together with the U-value, which are considered significant influencers of summer and winter behaviour 0], the overall picture of the preferred multilayered wall assembly becomes more complicated. The comparison of the (k_1) versus density shows that the massive wall assemblies will possess a higher value of internal area heat capacity (k_1), which is neither good nor bad. The higher internal area heat capacity (k_1) should provide more comfortable interior temperatures on a hot summer day due to its greater heat-accumulation capacity, and the decrement factor (*f*) should be as low as possible but not too low.

All the aforementioned evidence demonstrates that thermal inertia plays a crucial role in dynamic simulation and can be incorporated into multi-criteria optimisation and the pre-design assessment of building energy efficiency performance.

Conversely, as noted in [15], for nations experiencing hot summers, including Ukraine, which we can also place in this category, there has been a notable shift in climate conditions in recent decades. This has influenced the suggested range of dynamic thermal parameters, valid for energy-efficient envelopes with $\mathrm{U-value} < 0.3\,\frac{\mathrm{W}}{m^2\mathrm{K}}$ are $0.04 \le f \le 0.08$ for decrement factor (*f*) and $k1 \ge 40\,\frac{kJ}{m^2\mathrm{K}}$ for internal area heat capacity (k_1). This is also correlated with revealed recommendations for designers – a range of high thermal inertia levels $k1 \ge 30\,\frac{kJ}{m^2\mathrm{K}}$ for assemblies with no too low a decrement factor(*f*)~0.07 0].

To ensure the reliability of the results, the calculated dynamic parameters in Table 2 were compared with reference ranges reported in several relevant studies on the thermal inertia of building envelopes [4], [7], [13], [16], [30]. The values of the decrement factor (*f*) and internal area heat capacity (k1) fall within expected ranges for similar constructions, confirming the validity of the applied methodology.

To assess which of the assemblies examined in the current study align with the suggested ranges for both dynamic characteristics, a scatterplot in Figure 7 illustrates the relationship between internal area heat capacity ($k1$) and the decrement factor (*f*) for five different assemblies.

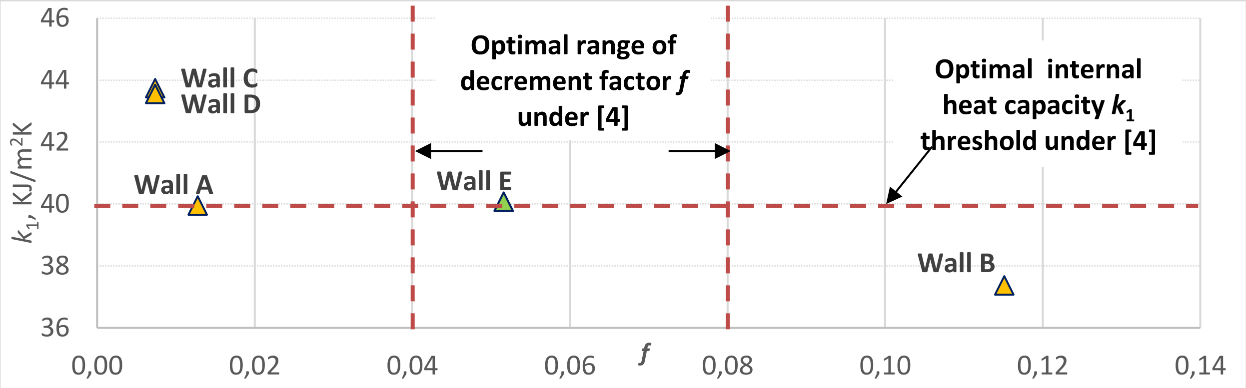

Figure 7 – Factual arrangement of researched assemblies in terms of recommended (k_1) and (*f*) values
Source: compiled by the authors

From Figure 7, it can be seen that only Wall E (marked in green) among the researched types of assemblies falls within the recommended range for the (k_1) and (*f*) values. Wall B has the highest decrement factor (*f*) and the lowest (k_1) value, indicating that it has the lowest damping effect on the incoming heat flow, according to [4]. Walls A, C, and D have too low a decrement factor (*f*), as the thermal wave attenuation marker, quantified by the dimensionless numbers – 0.013, 0.007 and 0.007, and good ($k1$) values 39.95, 43.74 and 40.07, kJ/m^{2}K respectively, which can be considered as “good thermal accumulators with low discharge intensity”, but it potentially could lead to summer overheating of the internal premise space [4].

To provide an additional criterion, which could ease the decision-making, the steady-state heat losses or multilayered wall assembly operational energy demand (OE), MJ/m^2 per year of particular assembly area, were accounted for and expressed in monetary terms (UAH/m^2 annually) by taking into account the current tariff for the supply of thermal energy for Vinnytsia city [46], as a potential construction site.

It should be noted that for Vinnytsia city, only the Heating Degree Days (HDD) period was accounted for in the OE calculation due to the high heating demand domination in the operation energy balance, due to the extended heating season that typically lasts from October to April, where the key climate metrics of the proposed city are given as follows:

– The city is located in central Ukraine;

– It has a humid continental climate, characterised by warm summers and no dry season (Köppen–Geiger Classification: Dfb [44]);

– Winters are cold, often with temperatures dropping below 0 °C, while average summer temperatures in July range from approximately 19 to 21 °C;

– Precipitation is fairly evenly distributed throughout the year [45];

– The climate is heating-dominated, with a typical annual Heating Degree Days (HDD) value of 3,676 °C·days/year, calculated using a base temperature T_base = 20 °C [45];

– Indicates a low requirement for cooling, with just brief instances of summer heat.

Meanwhile, the current edition of Norm [45] does not include Cooling Degree Days (CDD), but a rough assessment for a typical year could be calculated as D×(T_av-T_base)≈8×(23.5-22)≈12 °C·days/year, where D represents the number of days in the year when the average daily temperature Tav surpasses the threshold T_base = 22°C. It means that for the simplicity of the predesign calculation, we may neglect the CDD, which consist only $\frac{12}{3{,}676+12} \times 100\% \sim 0.3\%$ in total energy demand in the first coarse OE calculation.

To provide the transition from OE demand MJ/m^2 to the operational energy demand C_{OE} for 1m^2 of assembly expressed in UAH/m^2 per year, the formula (14) is proposed as follows

$$C_{OE} = U - value \times HDD \times 86400 \times C \times k, \tag{14}$$

Where C = 1314.08 UAH/Gkal, tariff for the heat supply service for Vinnytsia city, according to [46];

86400 – conversion coefficient from 24 h to seconds;

k = 1/4,184×10^9 – conversion coefficient from Gkal to Joule.

All C_{OE} calculations according to formula (14) are consolidated in Table 3.

Table 3

Calculated parameters for researched assemblies

Influence parameter	Wall type “A”	Wall type “B”	Wall type “C”	Wall type “D”	Wall type “E”
U-value, W/m^{2}K	0.17	0.15	0.15	0.22	0.17
C_{OE}, UAH/m^2	17.01	15.01	15.01	22.01	17.01

Source: obtained by the authors.

The analysis of the results of Table 3 demonstrates that operational energy cost C_{OE} is in direct correlation with U-value – the bigger this value, the bigger operational energy costs and vice versa. It is obvious, because the U-value is the only parameter in formula (14) that differs from wall to wall and depends on one’s material consistent layers.

Thus, since this research involves more than one characteristic to compare (in the current study, there are four calculated physical parameters plus one economic parameter), multicriteria decision analysis (MCDA) could be applicable, but in this research, the conceptual evaluation attitude is exclusively based on measurable physical parameters with emphasise on the dynamic thermal characteristics which can be a more objective comparison of different envelopes types in terms of their thermophysical and physical-mechanical parameters.

The core idea is to minimise as much as possible the subjectivity of any manipulations with obtained data, such as parameter weights, weighted sums, and other commonly used methodologies (AHP, PROMETHEE, TOPSIS, Grey Relation Analysis, etc.), that involve normalising the different parameters’ units for calculating the goal function (e.g. weighted aggregation). For this reason, the ranking of each parameter by a five-point grade was computed using the Excel RANK function to provide an “easier” and clearer picture for comparison of the proposed alternatives for the decision-maker (see Table 4).

Table 4

Ranking of researched assemblies*

Influence parameter	Wall type “A”	Wall type “B”	Wall type “C”	Wall type “D”	Wall type “E”
U-value, W/m^{2}K	3	1	1	5	3
m, kg/m^2	2	1	4	3	5
k_1, kJ/m^{2}K	4	5	1	2	3
f	3	5	1	1	4
C_{OE}, UAH/m^2	3	1	1	5	3

Source: compiled by the authors. *1- the “best”, 5 - the “worst”.

Analysis of the results in Table 4 reveals no overall “winner” or “best” assembly performance across all proposed criteria. Thus, Wall C has excellent grades in terms of U-value, decrement factor (f) and internal area heat capacity (k_1), but demonstrates poor mass value – grade 4, respectively. On the contrary, Wall B demonstrates “excellent” grades in terms of U-value and mass, but the “worst” dynamic parameters – $k1$ and f, respectively. Walls A, D, and E occupy intermediate positions in both U-value and dynamic characteristics grades. As an additional criterion, C_{OE} itself, due to its direct correlation with the U-value, doesn't provide any additional persuasive data for the final decision.

Discussion of the results of the research

The comparative analysis of the investigated multilayered wall assemblies reveals several fundamental aspects of their dynamic thermal behaviour under periodic boundary conditions:

Assessing the multilayered wall assemblies in terms of the proposed dynamic thermal performance (both the decrement factor (f) and the internal area heat capacity (k_1)) shows that only Wall E falls within the recommended range for these parameters, even with a moderate k_1 = 40.073 kJ/m^{2}K, despite the fact that all oft the multilayered wall assemblies meet Norm's [4] thermal resistance requirements.

Walls A, C and D demonstrate good internal area heat capacity (k_1), higher than in wall E (except for Wall A with 39.955 kJ/m^{2}K but also have too low decrement factor (f), namely 0.013, 0.007 and 0.007, respectively.

Notably, despite the fact that all the multilayered wall assemblies meet the current steady-state thermal resistance requirements for Ukraine $R_{qmin} = 4.0\ \frac{m^2\text{K}}{\text{W}}$, they behave differently in dynamic performance: Wall A, C and D have good heat wave attenuation effect, where only 1.3% and 0.7% of external heat-flux gains the interior (as it could be obtained from the f values for these multilayered wall assemblies). Wall B has the poorest heat-attenuating and heat-accumulating effect; namely, 11.5% of the heat flux is passed through the multilayered wall assembly, with a minimum internal area heat capacity (k_1) of 37.369 kJ/m^{2}K.

The results demonstrate that different comparable metrics can lead to non-obvious decisions about the "best" multilayered wall assembly, highlighting the inherently multi-objective nature of envelope design, even when based solely on the physical properties of envelope materials and accounting for dynamic thermal characteristics without cost values as proposed by C_{OE} criterion.

Despite significant differences in material composition, all multilayered wall assemblies exhibit the same order of magnitude in internal thermal response. The distribution of internal thermal mass governs the attenuation of thermal waves, quantified by the decrement factor (f), and the heat storage capacity, expressed by (k_1).

Overall, the study demonstrates that the dynamic thermal performance of building envelopes cannot be fully characterised by traditional parameters such as thermal transmittance or decrement factor (f) alone. Instead, an MCDA is required, incorporating (k_1) and (f) as a basis for optimising multilayered wall assemblies. This approach enables a more physically consistent interpretation of heat transfer processes and supports the development of energy-efficient and thermally stable building envelopes.

Conclusion

(1) The new parameters that can be used for providing early-stage assessment of envelope energy-efficiency performance, based exclusively on physical parameters of envelope materials, by considering dynamic thermal characteristics as a decrement factor (f) and internal area heat capacity (k_1), kJ/m^{2}K, were proposed in current research.

(2) The thermal transmittance coefficient (U-value) should be considered primarily during the early design stage as the primary determinant of envelope efficiency; however, this parameter alone fails to accurately reflect the dynamic thermal behaviour of constructions and their inertia-related performance.

(3) Dynamic thermal performance parameters, such as decrement factor (f) and internal area heat capacity (k_1), are valuable parameters for assessment of multilayered wall assemblies in the early design stage, in terms of the recommended ranges of both for different climate zones with $\text{U} - \text{value} < 0.3\,\frac{\text{W}}{m^2\text{K}}$, $0.04 \le f \le 0.08$ and $k_1 \ge 40\,\frac{kJ}{m^2\text{K}}$ for internal area heat capacity (k_1) for energy-efficient multilayered wall assemblies.

(4) The Wall E (ICF block) is the only one that met the recommended range of (f) and (k_1) for the five assemblies used in the research, while also exhibiting the highest mass.

(5) The Wall B (AAC) has the poorest dynamic performance in terms of heat-flux attenuating effect, (f = 0.115), which can lead to summer overheating, while the internal area heat capacity (k_1) is of the same magnitude as that of other multilayered wall assemblies, namely 37.369 kJ/m^{2}K.

(6) All the assemblies demonstrate similar steady-state U-value magnitude, but they behave differently in dynamic performance, and it can lead to a higher level of operation energy demand due to the dynamic

effect of exposure of the multilayered wall assemblies' materials and should be considered in optimised multilayer wall assemblies.

(7) Final decision-making policy of the decision-maker should be comprehensively based on physical, thermal and economic metrics of each assembly alternative, and a specific alternative can only be approved after considering an extra decisive criterion.

Current research revealed there is no clear winner among the five wall assemblies across all parameters, and only evaluation attitude, based on the Pareto-front of optimal solutions, comprehensively considering dynamic thermal characteristics, can provide an objective comparison of different multilayer wall assemblies in terms of their thermophysical and physical-mechanical parameters without any intervening manipulations with primary obtained results (data), which are commonly used in MCDA techniques when different units should to be normalised and compared on one scale.

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ПОРІВНЯННЯ ДИНАМІЧНИХ ХАРАКТЕРИСТИК ЕНЕРГОЕФЕКТИВНИХ БАГАТОШАРОВИХ ОГОРОДЖУВАЛЬНИХ КОНСТРУКЦІЙ

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У цій статті представлено підхід до оцінки динамічних характеристик багатошарових огороджувальних конструкцій будівель, зосереджуючись на фізично вимірюваних показниках теплотехнічних характеристик. На основі стандарту EN ISO 13786:2023 у дослідженні розглядаються коефіцієнт теплопередачі (U-value), внутрішня питома теплоємність (k1) та коефіцієнт загасання (f) як параметри теплових характеристик, а маса стіни як додатковий об'єктивний показник. П'ять стінових конструкцій, поширених на українському ринку - конопляний бетон (Костробетон), газобетон + мінеральна вата, цегляна кладка Porotherm + мінеральна вата, деревно-стружкові цементно-зв'язані блоки (Арболіт) та системи ICF (Блоки незйомної опалубки) - були оцінені за допомогою числового моделювання та порівняльного аналізу. Щоб усунути суб'єктивність у зважуванні критеріїв, чотири фізично значущі параметри порівнюються для визначення загальної оцінки. Результати показують, що стіна E (ICF) вважається динамічно збалансованою, ефективною конструкцією відповідно до параметрів внутрішньої питомої теплоємності та коефіцієнта загасання, проте вона має найбільшу масу серед інших конструкцій. Стіна B (Газобетон) продемонструвала найвищий ефект ослаблення теплового потоку – 0,115, що може призвести до літнього перегріву, тоді як стіна C (Порожниста цегла + утеплювач) та стіна D (Арболіт) показали подібну динамічну поведінку з надто низьким коефіцієнтом загасання – 0,007. Дослідження підкреслює складність об'єктивного багатокритеріального аналізу без вдавання до маніпуляцій з даними щодо проєктування огороджувальних конструкцій та надає фізично обґрунтовані критерії, які можуть сприяти більш об'єктивному прийняттю передпроєктних рішень. Поточні дослідження показали, що, хоча всі стіни відповідають вимогам ДБН України, стаціонарний коефіцієнт теплопередачі (U-value) можна розглядати лише на ранніх етапах прийняття рішень як ключовий параметр енергоефективності огороджувальної конструкції; однак, цей параметр сам по собі не може точно відобразити динамічну теплову поведінку конструкцій та їх інерційні характеристики.

Ключові слова: *динамічні теплові характеристики, багатошарова конструкція, оболонки, енергоефективність, фізичні параметри*

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