

THE DYNAMIC PERFORMANCE OF MULTILAYERED ENVELOPES

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Abstract

This paper introduces a set of new criteria for assessing the energy-efficiency potential of multilayered building envelopes, focusing on physically measurable aspects of dynamic thermal performance and LCA parameters. 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. 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 criteria weighting, physically meaningful criteria, such as internal areal heat capacity (k_1) and decrement factor (f) as thermal performance parameters, were proposed for comparison. Results indicate that only wall E (ICF) falls within the recommended thermal inertia range. The study highlights the complexity of MCDA in envelope design and provides physically grounded criteria that can support more objective predesign decision-making.

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

Introduction

The diverse range of building materials and construction techniques in modern practice has drawn significant attention from multicriteria decision analysis (MCDA) methods [1], particularly for determining building energy efficiency as broadly represented in papers [1], [2], [3], [4]. From a practical perspective, such research aims to identify criteria for energy efficiency that are both interpretable and adjustable [5]. Such criteria are results of complex interconnection of thermal and physical behaviour parameters of the multilayered envelope itself (e.g. U-value [5], [6], [7] thermal inertia [4], [8], [9], internal area heat capacity [5], [10] decrement factor [5], [9]), climate influence (e.g. hot degree days HDD, cool degree days CDD), building orientation towards the sun (e.g. Trombe wall in the south façade, opaque north-oriented wall [11]), etc. All of the studies mentioned above demonstrate that efforts to establish comprehensive criteria for evaluating envelope energy efficiency remain relevant [8]. Meanwhile, one of the major, if not the most crucial, ongoing pre-design stage challenges for developers is selecting the “best” option from the vast array of available building envelopes. However, comparisons between alternatives typically involve trade-offs, making the selection of the optimal or “best” solution inherently complex. The term “best” is used here with caution, as a multicriteria assessment of real-life alternatives often suggests that only options within the Pareto set can be deemed the “best” or optimal alternatives [2], [3], [4], [5], [12], [13]. In practice, new criteria could allow the decision-maker to pick the better Pareto-set solution that dominates others by this additional criterion, and provides the most advantageous overall compromise [13].

To facilitate the decision-making process during the early stages of building design, easily calculable physical criteria were chosen, including thermal transmittance (U-value), W/m^2K , mass (m , kg/m^2), decrement factor (f) and internal area heat capacity (k_1), kJ/m^2K , based on dynamic thermal performance standards outlined in Ukraine National Standard DSTU EN ISO 13786 [6] and embodied energy or primary energy of the wall component MJ/m^2 , as the objective LCA marker [14], [15].

Research results

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^2K , mass (m , kg/m^2), and internal area heat capacity (k_1), kJ/m^2K , as a dynamic thermal performance parameter under EN ISO 13786 [1] for the wall assembly, were taken.

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

For numerical simulation setup of the dynamic thermal performance efficiency parameters, as well of EE

parameter, 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 Figure 1, a detailed cross-section drawing is shown.

The dynamic thermal characteristics of each multilayered assembly were determined below under ISO 13786 6 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_i), decrement factor (f).

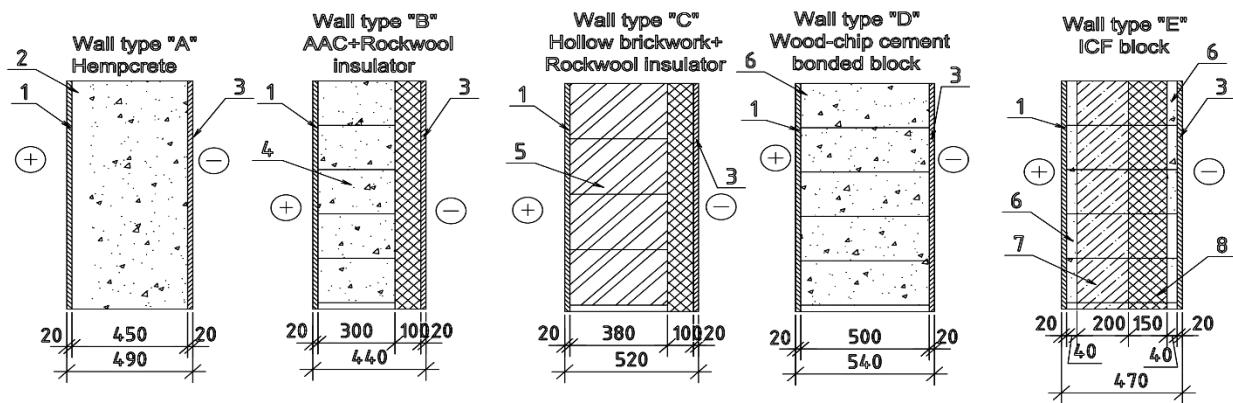


Fig. 1 Cross-sectional scheme of investigated wall assemblies: (1 - internal lime-sand plaster, 2 - hempcrete, 3 - external lime-sand plaster, 4 - aerated autoclaved concrete (AAC), 5 - hollow brickwork, 6 - wood-chip cement bonded block (woodcrete), 7 - reinforced concrete, 8 - BASF Neopor insulator)

The calculations were implemented in a spreadsheet environment [17] and verified through consistency checks and comparison with literature values (given below). The output influence parameters for all the assemblies are calculated in Table 1.

Table 1 – 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_i , 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

*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 $R_{qmin} = 4.0 \frac{m^2K}{W}$ 2727, or by a more convenient unit U – value = $\frac{1}{R_{qmin}} = 0.25 \frac{W}{m^2K}$ with significant energy efficiency potential (wall B and wall C, respectively, with the same U –

value = $0.15 \frac{W}{m^2K}$. Wall A and Wall E also demonstrate a sufficient level of U – value = $0.17 \frac{W}{m^2K}$. The last preferable Wall type from the perspective of thermal transmittance is Wall D with U – value = $0.22 \frac{W}{m^2K}$.

To ensure the reliability of the results, the calculated dynamic parameters were compared with reference ranges reported in several relevant studies on the thermal inertia of building envelopes [8],[15],[28],[29],[30],[31]. The values of the decrement factor and internal specific heat capacity fall within expected ranges for similar constructions, confirming the validity of the applied methodology.

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 [8], the overall picture of the preferred 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 (k_1) value should provide more comfortable interior temperatures on a hot summer day due to its greater heat-accumulation capacity.

On the other hand, as stated in 8, in the case of countries with a hot summer climate, to which, as we evident, Ukraine can also be enlisted, in retrospect of harsh climate changes, especially in the recent few decades, the recommended range of dynamic thermal parameters, valid for energy efficient envelopes with $U - value < 0.3 \frac{W}{m^2K}$ are $0.04 \leq f \leq 0.08$ for decrement factor and $k_1 \geq 40 \frac{kJ}{m^2K}$ for internal area heat capacity. This is also correlated with revealed recommendations for designers – a range of high thermal inertia levels $k_1 \geq 30 \frac{kJ}{m^2K}$ for assemblies with no too low a decrement factor value $f \sim 0.07$ [8].

To determine which of the assemblies considered in current research meet the recommended ranges for both dynamic characteristics, a scatterplot in Figure 2 shows the dependence of internal area heat capacity (k_1) on the decrement factor (f) for five assemblies.

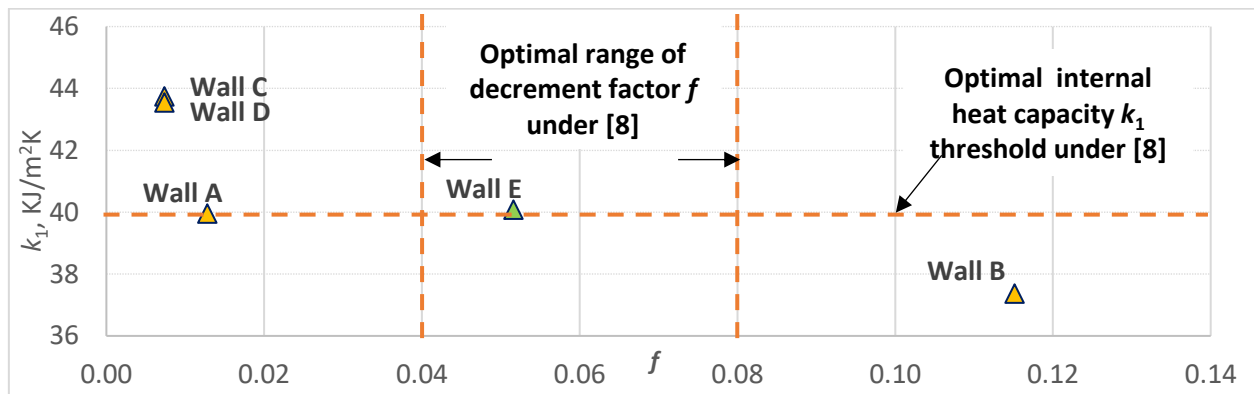


Fig. 2 – Factual arrangement of researched assemblies in terms of recommended (k_1) and (f) values

From Figure 2, it can be seen that only Wall E (marked in green) of all the researched types of assemblies falls within the recommended range of 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. Walls A, C and D have a low decrement factor (f) with a good (k_1) value.

Thus, since this research involves more than one characteristic to compare (in the current study, there are four physical parameters), multicriteria decision analysis (MCDA) could be used.

Conclusions

Dynamic thermal performance parameters, such as, but not restricted to, decrement factor (f) and internal area heat capacity (k_1) , are valuable parameters for effective assembly design in the early multilayered design stage, by utilising the recommended ranges of both for different climate zones, respectively, for energy-efficient envelopes with U -value $< 0.3 \frac{W}{m^2K}$, such as $0.04 \leq f \leq 0.08$ and $k_1 \geq 40 \frac{kJ}{m^2K}$ for internal area heat capacity for hot climates. In the current research, 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.

Current research can be determined as the next step in the conceptual evaluation attitude, exclusively based on measurable physical parameters of envelope materials considering dynamic thermal characteristics, which can provide a more objective comparison of different envelopes types in terms of their thermophysical and

physical-mechanical parameters, by elimination of the subjectivity of parameter weights, weighted sums, and other commonly used data manipulations that involve different units for calculating the goal function (e.g. weighted aggregation).

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