UDC 697.13

Y. Biks[1]

THE PARETO FRONTIER APPROACH FOR THE SEARCH OF ENERGY-EFFICIENT MULTILAYERED ENVELOPES

[1] Vinnytsia National Technical University

Abstract

This paper outlines a methodological toolset for policy decision-making on the choice of multilayered building envelopes, focusing on physically measurable dynamic thermal performance and Life Cycle Energy Analysis (LCEA) parameters. Based on the DSTU EN ISO 13786:2023 Code, the current framework limits key thermal performance parameters to thermal transmittance (U-value), internal areal heat capacity (k_1), and the decrement factor (f). The objective function, total energy (E_{tot}), comprises operational energy (E_{oper}) and embodied energy (E_{emb}) demands, along with constraints such as assembly mass, width, and U-value. Five multilayered assemblies - Hempcrete, AAC, Porotherm brickwork, Arbolit (wood-chip cement-bonded blocks) and one ICF system were numerically evaluated and analysed in a modelling comparison. Results indicate that only wall B (AAC) demonstrates minimum E_{tot} falls within the constraints range. The study highlights the complexity of satisfying both the thermal performance and energy-efficiency demand with being optimal in both. As well current research provides clear framework for predesign objective decision-making.

Keywords: Dynamic thermal performance efficiency, Pareto-frontier, Multilayered assembly, Optimal non-dominated solution, Energy efficiency, Physical parameters

Introduction

The increasing diversity of building materials creates many physically meaningful multilayered envelope configurations, making the selection of energy-efficient wall assemblies a challenging multicriteria optimisation problem. Previous studies [1–4] have shown that multicriteria decision analysis (MCDA) can assess building energy performance and select sustainable construction solutions. However, the search for a single "best" envelope is complicated by the conflicting nature (as usual) of its thermal, physical, and environmental characteristics. Improving one performance indicator may require compromises in others, making conventional single-criterion optimisation insufficient for identifying well-balanced design alternatives [2, 3, 5].

In this context, the current Pareto-frontier approach provides a systematic framework for exploring competing design objectives without imposing predefined subjective weighting factors. A solution is considered Pareto-optimal when no objective can be improved without deteriorating at least one other objective [6]. Consequently, instead of identifying a single optimum, the optimisation process generates a set of non-dominated alternatives that represent different trade-offs among the considered performance criteria. This distinction is particularly important at the early design stage, when material selection, layer sequencing, and geometric parameters remain adjustable. The resulting Pareto frontier lets designers examine the consequences of alternative design choices and select a preferred compromise based on project-specific requirements.

On the other hand, the energy performance of multilayered envelopes depends on the complex interaction of their steady-state and dynamic thermal characteristics, including thermal transmittance(*U*-value [5, 7], thermal inertia [4, 8, 10], internal areal heat capacity k_1 [8, 10], and decrement factor f [8, 9, 11]. Material properties, layer thicknesses and arrangement, climatic conditions and building orientation influence these characteristics [11]. Furthermore, minimising operational energy demand does not necessarily minimise embodied energy (in fact, vice versa), particularly when additional insulation or material-intensive solutions are introduced [12, 13]. Therefore, a meaningful optimisation framework should account for both energy-related objectives and the physical constraints governing the feasibility of envelope configurations.

Despite the growing use of multicriteria approaches in building design, identifying Pareto-optimal multilayered wall assemblies using a consistent combination of physically interpretable thermal-performance indicators and life-cycle energy considerations remains an important research task. Accordingly, this study uses a Pareto frontier search strategy to evaluate alternative multilayered

envelope configurations. Thermal transmittance (U, W/(m²·K)), areal mass (m, kg/m²), decrement factor f, and internal areal heat capacity (k_1, kJ/(m²·K)) are considered as physically meaningful performance indicators and design constraints, with dynamic thermal characteristics determined in accordance with DSTU EN ISO 13786:2023 [14]. Embodied energy (E_{emb}, MJ/m²) is incorporated as a life-cycle-related energy indicator [12, 13]. The proposed approach aims to identify technically feasible, non-dominated envelope configurations and provide a transparent basis for selecting energy-efficient wall assemblies while explicitly accounting for trade-offs among competing performance requirements.

Research results

In the current research, five types of multilayered wall assemblies (see detailed cross-sections in Figure 1), were tested, namely: Wall A (Hempcrete), Wall B (Aerated autoclaved concrete (AAC) D300 + Rockwool as insulation material); Wall C (Hollow brickwork masonry (Porotherm 38) + Rockwool as insulation material), Wall D (Wood-chip cement bonded block) and Wall E (wood-chip cement bonded block, as type of Insulated concrete formwork (ICF).

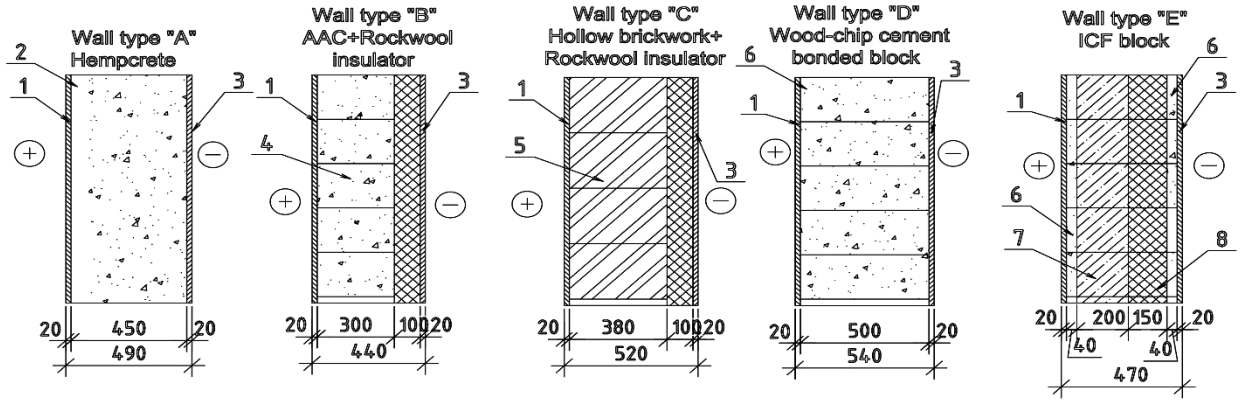


Fig. 1 Cross-sectional scheme of investigated wall assemblies: (1 - Internal lime-sand plaster, 2 - Hemcrete, 3 - External lime-sand plaster, 4 - AAC, 5 - hollow brickwork, 6 - Wood-chip cement bonded block (Arbolit), 7 - Reinforced concrete, 8 - BASF Neopor insulator)

Key physical, easily calculable parameters were used for early-stage multi-layered assembly design, such as U-value, W/m²K, assembly mass m (kg/m2), f, and k_1 as dynamic thermal performance parameters under [14]. The numerical assessment of dynamic thermal performance efficiency parameters was performed using the HTflux [15] Excel-based calculator spreadsheets, which are freely downloadable.

In this study, as an objective function, the minimisation of total energy E_{tot} was suggested, which is the sum of energy required for two life-cycle parts of the building construction - material production (i.e. embodied energy) and operational energy consumed during the building service life, as shown in Equation (1):

$$E_{tot} = E_{emb} + E_{oper} \rightarrow min,, \quad (1)$$

where E_{emb} reflects the embodied energy amount of the multilayered assembly, MJ/m² (for the scope of this study, the framework is restricted to A1-A3 stages of LCEA only, where A1 - Raw Material Supply, A2 - Transport to Manufacturer, and A3 – Manufacturing);

E_{oper} is the envelope operational energy demand, MJ/m², over the adopted evaluation period (in this study, the envelope operational period is set to T_{op} = 50 years for the city of Vinnytsia. For the purpose of the current research, the constraints and multi-layered material thicknesses were adopted (Tab. 1 and Tab. 2, respectively).

Table 1 – Optimisation constraints

Parameter	Constraints
Overall envelope width, m	≤ 0.7
Overall envelope mass, kgm^{-2}	≤ 500
Internal area heat capacity k_1, [kJm^{-2}K^{-1}]	≥40
U-value, [Wm^{-2}K^{-1}]	≤ 0.25
Decrement factor f, [-]	[0.019; 0.08]

Table 2 – Material thicknesses range

Material	Thickness range
Lime-sand plaster thickness, m	[0.01; 0.05]
Hempcrete thickness, m	[0.1; 0.5]
AAC thickness, m	[0.2; 0.4]
Hollow brickwork masonry thickness, m	[0.25; 0,38; 0.51] discrete values
Wood-chip cement-bonded block thickness, m	[0.1; 0.5]
Wood-chip cement-bonded block (ICF) framework thickness, m	[0.03; 0.06]
Reinforced concrete (RC) infill core thickness, m	[0.12; 0.2]
Neopor insulator thickness (EPS), m	[0.1; 0.3]
Rock wool wall insulator thickness, m	[0.1; 0.3]

The thickness step applied in the model is within the assigned range; the discrete values of Porotherm blocks are taken from the manufacturer's data [16]. The dynamic thermal characteristics of each multilayered assembly were determined under [14]; the Pareto-frontier search under the applied constraints for the city of Vinnytsia was calculated using a Python-based script on Kaggle. The final Pareto-frontier, constructed under the aforementioned constraints, is shown in Fig. 2.

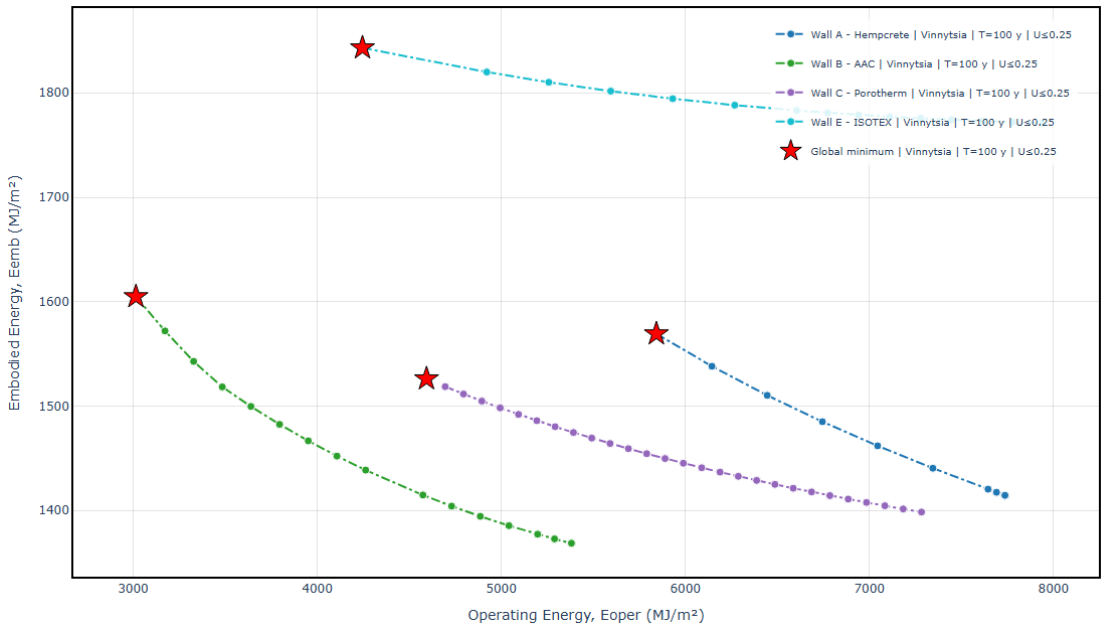


Fig. 2 – Pareto frontier comparison for researched assemblies

Figure 2 illustrates the relationship between operational energy E_{oper} and embodied energy E_{emb} for the investigated multilayered wall assemblies. A consistent trade-off is observed within each assembly family: lower operational energy demand is generally associated with higher embodied energy, reflecting the additional material requirements for improved thermal performance.

Among the configurations displayed, Wall B (AAC + Rockwool) demonstrates the most favourable energy performance, with the lowest operational energy demand and comparatively low embodied energy. Its Pareto curve occupies the lower-left region of the objective space and appears to dominate the other plotted assembly families. Conversely, Wall E (ICF) exhibits the highest embodied energy despite its relatively favourable dynamic thermal characteristics.

Conclusions

The conducted numerical investigation demonstrates the applicability of the Pareto-frontier approach to the multicriteria assessment of energy-efficient multilayered building envelopes. However, an energy-optimal wall assembly is not necessarily thermally admissible, and conversely, satisfying dynamic thermal-performance criteria does not guarantee minimum life-cycle energy demand. Thus, the Pareto-frontier approach reveals these trade-offs and identifies non-dominated alternatives within a physically constrained design space.

Current research is the next step in evaluating of simultaneous non-dominated energy-optimal and dynamic thermal-performance decision space, with an objective function based exclusively on measurable physical parameters and reasonable constraints, providing a tool for early comparison of different envelope types by their thermophysical parameters.

REFERENCE LIST

1. Thakkar, J. J. (2021). Multi-criteria decision making (Vol. 336, pp. 1-365). Singapore: Springer. https://doi.org/10.1007/978-981-33-4745-8
2. Basińska, M. (2017). The use of multi-criteria optimization to choose solutions for energy-efficient buildings. Bulletin of the Polish Academy of Sciences. Technical Sciences, 65(6). https://doi.org/10.1515/bpasts-2017-0084
3. Wang, J. J., Jing, Y. Y., Zhang, C. F., & Zhao, J. H. (2009). Review of multi-criteria decision analysis in aid of sustainable energy decision-making. Renewable and sustainable energy reviews, 13(9), 2263-2278. https://doi.org/10.1016/j.rser.2009.06.021
4. Biks Y., Ratushnyak, G., & Ratushnyak, O. (2019). Energy performance assessment of envelopes from organic materials. Architecture, Civil Engineering, Environment, 12(3), 55-67. https://doi.org/10.21307/acee-2019-036
5. Auf Hamada, A., Raslan, R., & Hong, S. (2023). A framework for parametric multi-criteria decision analysis (P-MCDA) for building retrofits. Building Simulation Conference Proceedings. https://doi.org/10.26868/25222708.2023.1519
6. Kovalenko, I., Davydenko, Y., Shved, A. (2020). Searching for Pareto-Optimal Solutions. In: Shakhovska, N., Medykovskyy, M.O. (eds) Advances in Intelligent Systems and Computing IV. CSIT 2019. Advances in Intelligent Systems and Computing, vol 1080. Springer, Cham. https://doi.org/10.1007/978-3-030-33695-0_10
7. Brojan, L., Petric, A., Clouston, P. L. (2013). A comparative study of brick and strawbale wall systems from environmental, economic, and energy perspectives. ARPN Journal of Engineering and Applied Sciences, 8, 920–926.
8. Ukrainian National Standard. DSTU EN ISO 13786:2023 Thermal performance of building components – Dynamic thermal characteristics – Calculation methods (2023). (Official edition) Kyiv: Institute of Technical Thermophysics of the National Academy of Sciences of Ukraine (in Ukrainian).
9. Alkhatib, H., & Lemarchand, P. (2024). Assessing Thermal Performance: An Experimental Study on U-Value Variability in Building Fabric Elements. Results in Engineering. https://doi.org/10.1016/j.rineng.2024.103730
10. Stazi, F. (2017). Thermal Inertia in Energy Efficient Building Envelopes. Butterworth-Heinemann. https://doi.org/10.1016/C2016-0-00641-1
11. Stazi, F., Ulpiani, G., Pergolini, M., & Di Perna, C. (2018). The role of areal heat capacity and decrement factor in case of hyper insulated buildings: An experimental study. Energy and Buildings, 176, 310-324. https://doi.org/10.1016/j.enbuild.2018.07.034
12. Asdrubali, F., Grazieschi, G., Roncone, M., Thiébat, F., & Carbonaro, C. (2023). Sustainability of Building Materials: Embodied Energy and Embodied Carbon of Masonry. Energies. https://doi.org/10.3390/en16041846
13. Reilly, A., Kinnane, O., & O'Hegarty, R. (2020). Energy embodied in, and transmitted through, walls of different types when accounting for the dynamic effects of thermal mass. Journal of Green Building, 15(4), 43-66. https://doi.org/10.3992/jgb.15.4.43
14. Ukrainian National Standard. DSTU EN ISO 13786:2023 Thermal performance of building components – Dynamic thermal characteristics – Calculation methods (2023). (Official edition) Kyiv: Institute of Technical Thermophysics of the National Academy of Sciences of Ukraine (in Ukrainian).
15. A brief guide and free tool for the calculation of the thermal mass of building components. Retrieved February 18, 2026, from: https://www.htflux.com/en/free-calculation-tool-for-thermal-mass-of-building-components-iso-13786/
16. Porotherm wall solutions [Internet]. 2025 [cited 2025 Jul 20]. Available from: https://porotherm.com.ua

Biks Yuriy **–** Cand. Sc. (Eng), Associate Professor of Construction, Urban Economy and Architecture Department, Vinnytsia National Technical University, Vinnytsia,email : biks@vntu.edu.ua