DOI: 10.59647/978-617-520-936-3/1

Decomposition of the building as a single energy system and the impact of the massive factor of the structure on such a system

Oleksandr Pohosov, Ph.D, associate professor (ORCID: 0000-0003-2158-8897) [1], **Pavlo Pasichnyk,** Ph.D, associate professor (ORCID: 0000-0001-8499-6949) [1], **Bohdan Kozyachyna,** Ph.D student (ORCID: 0009-0000-6972-3862) [1], **Artemiy Sokhatyuk,** student (ORCID: 0009-0002-2060-1308) [1].

[1]*Kyiv National University of Construction and Architecture, ave. 31 Povytryaniy Sil, Kyiv, Ukraine*

ABSTRACT

This paper provides a detailed analysis of the decomposition of a building's energy system, with a focus on the impact of structural massiveness on energy performance. The study investigates the interaction between various building subsystems, including external climate factors, the building envelope, and internal structures, to assess their contribution to overall energy dynamics. Particular attention is given to the role of the massiveness of the enclosing structures in reducing the rate of building cooling, which may form the basis for optimizing design solutions aimed at improving energy efficiency and reducing heating and ventilation costs. Modeling temperature changes in emergency modes and analyzing heat flows lead to conclusions about improving comfort and building resilience to operational condition changes. The use of combined approaches to thermal forecasting, integrating different mathematical models, helps improve long-term energy consumption predictions for buildings, which is a critical factor for modern energy management systems.

Keywords: Building energy system, decomposition, energy efficiency, heat balance, prediction models, thermal comfort, hybrid model, external climate factors, massiveness of structures, heating and ventilation systems.

1. INTRODUCTION

Decomposing a building as a single energy system provides a comprehensive understanding of how various components interact to affect overall energy performance. By carefully analyzing and optimizing these interactions, one can enhance energy efficiency, reduce costs, and promote sustainability.

Today, there is a significant number of works that apply different approaches to the integrated analysis of a building as a single energy system. An accuracy prediction model contributes significantly to the improvement of building energy efficiency and flexibility.

2. OBJECTIVE

The aim of this article is to analyze and model a building as a single energy system, taking into account the impact of the massiveness of the enclosing structures on energy efficiency. The research focuses on studying the interconnections between the external environment, the enclosing structures, and the internal environment of the building to optimize energy performance, reduce energy costs, and enhance the resilience of building systems to operational condition changes.

3. THE MAIN STUDY

However, most existing prediction models are either based on single time series model or static model, making them perform poorly for long-term predictions. Papers [1, 2] propose a hybrid prediction model, which combines the deep ensemble (DE) model and autoregressive (AR) model together.

The decomposition of a building as a single energy system can be represented by three main energy interconnected subsystems [3], each of which may also contain various sources of energy supply and loss:

- Energy impact of external climate factors on the building envelope.
- Energy contained in the building envelope, i.e. the external building envelope.
- The energy contained within the building volume, i.e. in the internal air, internal equipment, load-bearing and non-load-bearing internal structures.

Figure 1 shows a graph of the building's heat balance, which provides a comprehensive overview of the decomposition method.

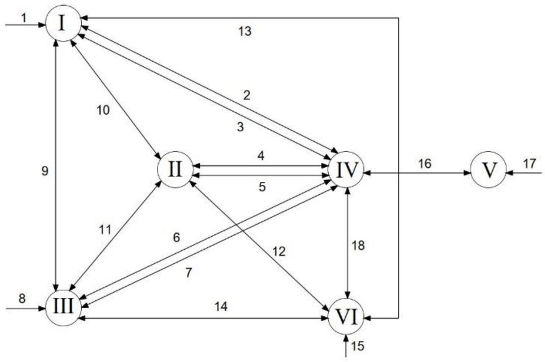

Figure 1. Heat balance graph of a room: I - external envelopes, II - internal envelopes, III - filling of the skylight, IV - internal air, V - ventilation, VI - internal equipment. Links 2, 4, 6, 8 characterise the heat transfer by convection between the inner surface of the envelope, as well as the surface of the equipment and the internal air, links 3, 4, 5, 7 characterise the heat flows due to filtration through the envelope, links 9-14 characterise the radiation heat transfer between the internal surfaces of the envelope and the internal surfaces with the equipment, link 16 characterises the convective heat directly transferred to the room air, links 1, 8, 15, 17 - external links between the room element and the external element

Accordingly, the following tasks are relevant in the context of the issue of decomposition of the building energy system:

- Modelling the decrease in building temperature in emergency or standby modes of the heating system operation: decrease in building temperature depending on the massiveness of the building and depending on the air exchange rate.
- Influence of the placement of heating devices (traditional and near massive load-bearing structures) on the microclimate parameters and energy performance of the building.
- Modelling the change in the resulting temperature as a factor affecting human thermal comfort, depending on the combination of convective and infrared components of the heating system.
- Comprehensive studies of the impact of individual elements of heating and ventilation systems on the energy performance of a building.

Using the graph model in Figure 1 and decomposition [3], the dependence (1) of the temperature difference between the external and internal environments on a number of factors related to the cooling of the building, described in detail in [4, 5], was chosen.

$$\Theta_{в} = \Theta_0 \exp\left(\frac{-2A}{B}\cdot(t)^{\frac{1}{2}}\right) \quad (1)$$

where: Θ_0 – Initial temperature difference between indoor and outdoor air, °C; A and B – criteria that are determined by dependencies (2-3); t – time, s.

$$A = L\cdot c_{air}\cdot\frac{\rho_{air}}{3.6} + K_{лбі}\cdot A_{лбі} \quad (2)$$

where: L – infiltration (in case of emergency cooling) or ventilation (in normal operation of the building) air flow rate, m^3/hour; $A_{лбі}$ – area of external enclosing structures, m^2; $K_{лбі}$ – consolidated heat transfer coefficient of building envelopes, W/m^2*K; c_{air} i ρ_{air} – heat capacity (kJ/kg*K) and air density (kg/m^3).

$$B = A_{mi}\cdot(\lambda\cdot c\cdot\rho)^{\frac{1}{2}} \quad (3)$$

where: A_{Mi} – area of internal building structures, m^2; λ, c and ρ – thermal conductivity (W/m*K), heat capacity (kJ/kg*K) and density (kg/ m^3) of wall material.

In accordance with dependence (1), the results of cooling of a conditional 'two-room' building with three structurally load-bearing walls with a total building area of 50 m^2 were obtained in variations with internal structures made of materials of different densities. The results of this modelling are shown in Figure 2.

4. CONCLUSION

In this article, the importance of considering a building as a complex energy system composed of three main factors is emphasized: the influence of the external environment, the energies of the building's external structures, and the internal environment, including load-bearing elements. It is crucial to note that each of these aspects interacts with one another, affecting the overall energy balance.

Specifically, an increase in the massiveness of the building has significant implications for cooling: more massive structures exhibit a slower cooling rate. This opens up the possibility to reconsider design approaches regarding the external environmental temperature, which in turn may lead to substantial reductions in capital investment for engineering systems. Decreasing the rated capacity, as calculated, will allow for optimization of energy costs and improve the overall efficiency of buildings.

Thus, examining these aspects can contribute to the development of new design strategies that not only ensure energy efficiency but also enhance the economic viability of construction. These results highlight the need for integrating energy and architectural approaches to achieve sustainable development in the construction industry.

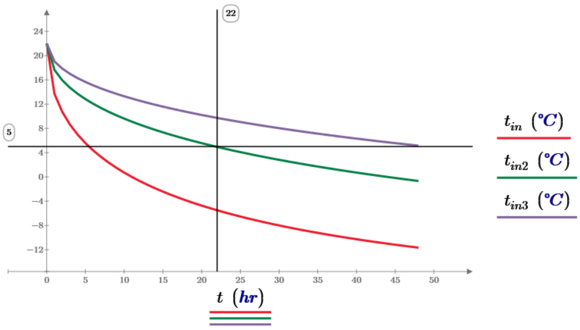

Figure 2. The change in internal air temperature when the heating system is turned off according to the dependence [4] with a variation in the linear dimensions of the internal load-bearing massive structures, t_{in} corresponds to 35 m^2 of wall (one partition 10 m long), t_{in2} - 70 m^2 of wall (two partitions 10 m long), t_{in3} - 105 m^2 of wall (three partitions 10 m long)

References

[1] Liang X., Chen S., Zhu X., Jin X., & Du Z. Domain knowledge decomposition of building energy consumption and a hybrid data-driven model for 24-h ahead predictions. *Applied Energy*. 2023. 344. P. 121–244.

[2] Eisenhower B., O'Neill Z., Fonoberov V. A., & Mezi I. (). Uncertainty and sensitivity decomposition of building energy models. *Journal of Building Performance Simulation*. 2012. 5(3). P. 171–184.

[3] Tabunschikov Y. A. Mathematical Models of Thermal Conditions in Buildings, Boca Raton. Florida: CRC Press, 1993.

[4] Horikiri K., Yao Y., & Yao J. Modelling conjugate flow and heat transfer in a ventilated room for indoor thermal comfort assessment. *Building and Environment*. 2014. 77. P. 135–147.

[5] Monstvilas E., Stankevičius V., Karbauskaitė J., Burlingis A., & Banionis K. Hourly calculation method of building energy demand for space heating and cooling based on steady-state heat balance equations. *Journal of Civil Engineering and Management*. 2012. 18(3). P. 356–368.