Vol. 4, No. 1, 2022

https://doi.org/10.23939/jtbp2022.01.057

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ALTERNATIVE HEAT SYSTEMS FOR MODULAR BUILDINGS

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At present, the problem of energy-saving construction remains extremely relevant. The use of alternative energy sources for heat supply of buildings and structures is one of the ways to solve the problem of rational use of fuel and energy resources.

This article considers effective methods of using solar energy with the help of thermosyphon solar collectors integrated into the external enclosing structures of a modular house.

The research results showed that for efficient operation of the thermosyphon collector the area of ventilation openings should be within 0.005–0.06 m^2.

Key words: thermosyphon solar collector; modular house; solar energy; energy efficiency; microclimate parameters; infrared rays; alternative energy.

Introduction

The issues of reducing the cost of fuel and energy resources and reducing the impact on the environment, as well as the timing of projects, today are more than relevant for construction companies and are reflected in modern "modular construction", and therefore Ukraine should pay attention on this modern building system, as one of the ways to solve the problem of lack of new and resettlement of old living space.

An important issue in the development of modular buildings is the problem of maintaining the thermal condition of the premises. The possibility of autonomous provision of such facilities with energy resources should be taken into account. This is possible with the use of alternative energy sources such as solar and geothermal energy, and if possible – wind and biogas energy. Thus, at the moment, modular construction technologies require a comprehensive approach to addressing energy efficiency and providing the necessary microclimate parameters in such buildings.

Materials and Methods

A modular building is a building that is assembled from one or more sections-modules of factory production directly on the land of the owner. The blocks have openings for windows, doors and communications. In most cases, the modules are delivered to the assembly site with external finishing, sometimes only in the form of a frame, which is assembled directly on site.(Huang, 2007; Majumder, A., 2021; Sanchez Benjamina, 2022, Zhelykh, V., 2016)

Modular house: materials of manufacture the basis of such a building is a wooden, metal or combined frame. Protection against moisture, steam and wind, a layer of sound insulation keep within external protections. Foam, basalt or mineral wool is used as insulation. All this is covered with sheet materials (vinyl or metal siding, wooden beams, composite panels, etc.) in DSTU-N B B.2.5-43: 2010, DBN B.2.6-31.2006 and DBN D.1.1-2-99. The cladding is covered with special solutions or a layer of structural plaster. Any material that is compatible with the actual project is often chosen for interior decoration. Preference is given to light and practical building materials: decorative plaster, panels, laminate, wood paneling, drywall and the like. Windows are usually used plastic, they can be both panoramic and dormer type (Marza, Carmen, 2019; Dennis Holloway, 2003; Miciuła I., 2020; Ferdous, W., 2019, Patrik Jensen, 2010).

Modern modular structures are made of quality and environmentally friendly materials. Wood, metal, insulation and panels – everything that can be found in an ordinary apartment or cottage. Therefore, living in such houses is not harmful to both the owners and the environment (Ulewicz M., 2020; Ulewicz M., 2021, Shapoval, S., 2017; George-Lucian Ionescu, 2017).

In Ukraine, the production of high-quality, high-tech modular housing has not yet been established. Few enthusiasts of modular production are forced to work in unstable socio-economic conditions; manufactured products are not available to the mass consumer. The architectural and spatial environment of Ukrainian cities so far is almost devoid of modern modular housing elements (Energy sources in Ukraine, 2017; Zero-Energy Buildings, 2014; Alternative Energy Sources, 2003; J. Foster, 2016).

Results and discusions

The purpose of experimental studies conducted in the laboratory was to determine the thermal capacity of the thermosyphon solar collector at a variable thickness of the air layer and the area of the vents.

Experimental studies were conducted to analyze the processes of formation of the parameters of the thermal regime in the thermosyphon collector; determination of necessary values of influencing factors, in particular ambient temperature, air mobility and intensity of solar radiation;

According to the analysis of the processes of formation of the thermal regime, the following tasks of experimental research were set: to establish the patterns of thermal power of the thermosyphon solar collector at different thicknesses of the air layer.

The experimental study to determine the thermal capacity of the thermosyphon solar collector was conducted on the basis of experimental planning taking into account such factors as the thickness of the air layer and the area of the inlet and outlet openings.

A fragment of the room of a modular house with a hybrid exterior in which a thermosyphon solar collector is installed is shown in Fig. 1.

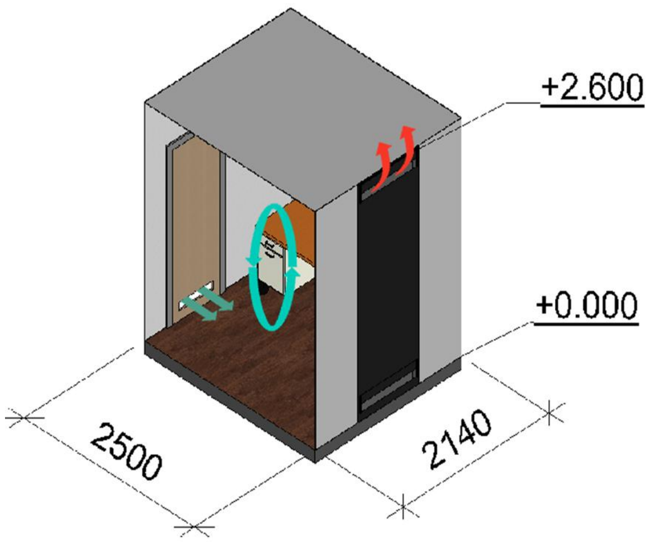

Fig. 1. Premises of a modular house with an integrated thermosyphon solar collector for external protection

To conduct research, an experimental installation was developed, which was made in full size from the same structural materials as the external protection of a modular building (Fig. 2).

Fig. 2. Photo of the research installation in the laboratory of Lviv Polytechnic National University

Infrared rays heat the metal plate 2, due to the temperature difference there is a "thermosyphon effect" (the phenomenon of free convection), ie cold air from the room through the lower hole enters the collector, heats up and due to the difference in density rises, and heated returns to the room outlet. The speed and volume of air passing through the collector housing are equalized by adjusting the distance of the steel plate and dampers. The scheme of the experimental setup is shown in Fig. 3.

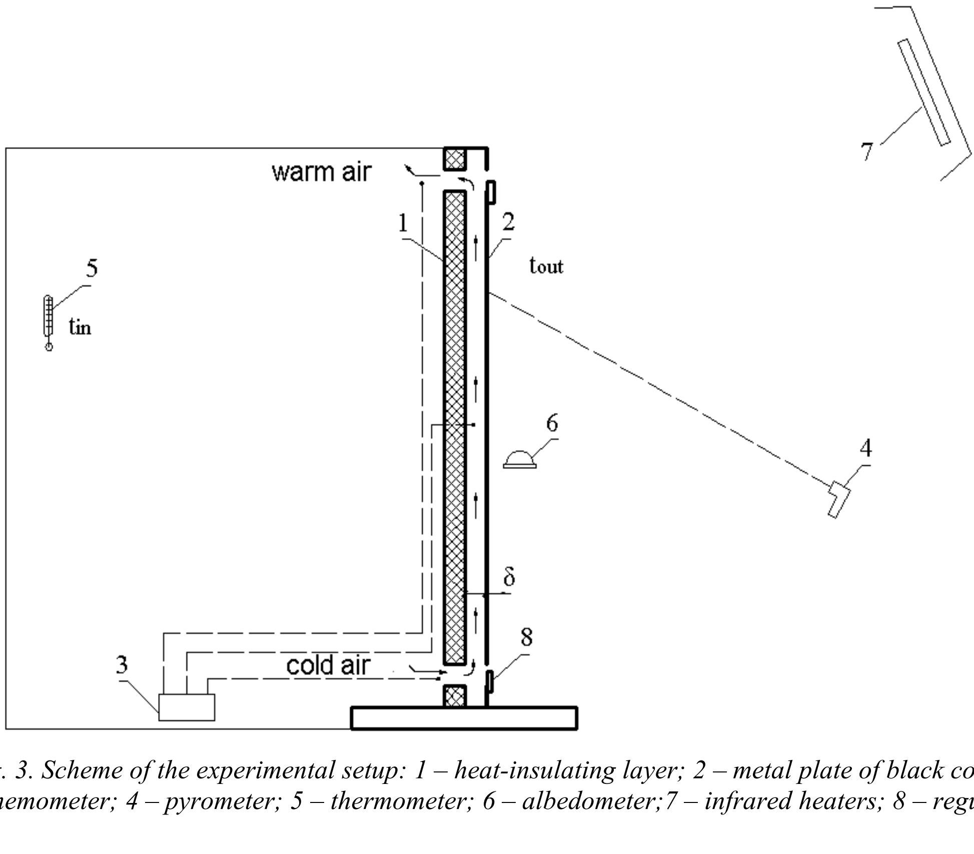

Fig. 3. Scheme of the experimental setup: 1 – heat-insulating layer; 2 – metal plate of black color; 3 – thermoanemometer; 4 – pyrometer; 5 – thermometer; 6 – albedometer;7 – infrared heaters; 8 – regulating valves

The research methodology is presented below.

Laboratory tests were performed in a sealed module with an area of 5.4 m^2 and a volume of 14 m^3, which simulated a living space.

The procedure for conducting the research was as follows:

1. First, infrared (IR) heaters (7) were turned on, and the temperature of the metal plate (2) was measured with a pyrometer.
2. The temperature and air velocity from the outlet, inlet and in the middle of the installation were measured every 10 min for 8 h using a thermoanemometer (3).
3. The intensity of infrared radiation was measured with an albedometer.
4. Depending on the interplate distance δ m and the radiation intensity I = const W/m^2, the experiments were repeated.
5. The research results were processed.

In order of processing the results the heat consumption for heating infiltrative outdoor air in residential and public buildings for all premises is determined from two calculations.

The first calculation determines the heat consumption Q_i for heating the outside air entering the i-th room due to the operation of natural exhaust ventilation.

To determine the estimated heat loss of the premises take the largest value of those defined by the following formulas (1) and (2).

$$Q_i = 0{,}28\ L\ \rho_{out}\ c\ (\ t_{in} - t_{out}), \tag{1}$$

where L is the exhaust air flow rate, m^3/h, accepted for residential buildings 3 m^3/h per 1 m^2 of living space and kitchen; ρ_{out} – density of outside air, kg/m^3; c –specific heat of air equal to 1 kJ/(kg°C).

The specific weight γ, N/m^3 and air density ρ, kg/m^3, can be determined by the formulas:

$$\gamma = 3463/(273 + t)\ ,\ \rho = \gamma/g\ , \tag{2}$$

where t is the air temperature, °C; g = 9.81 m/s^2.

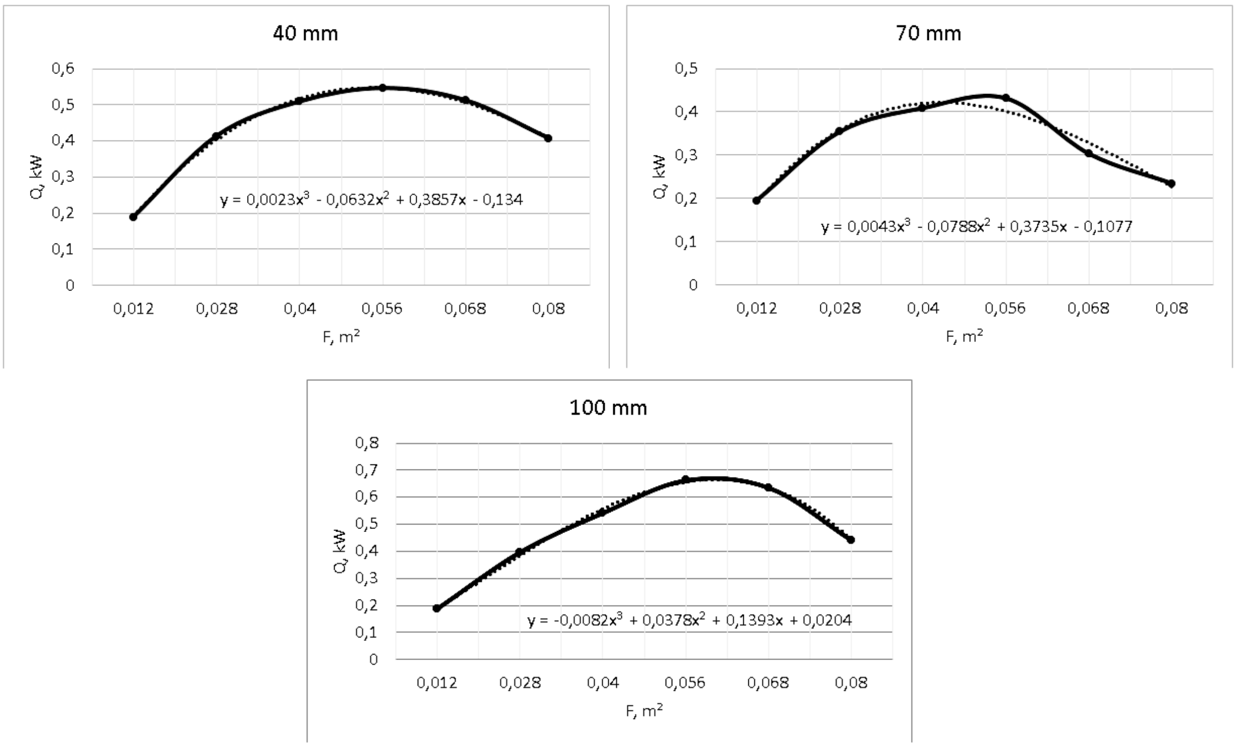

Fig. 4. Graphs of the dependence of thermal power (Q) on the area of the inlet and outlet holes (F), as well as the thickness of the layer (δ)

The results of experimental studies are shown in Fig. 4, which were obtained on the basis of statistical processing, the graphical dependences of the thermal power of the thermosyphon solar collector were obtained depending on the thickness of the air layer δ and the area of the ventilation holes F.

From the graphic dependences it can be seen that for the thermosyphon solar collector it is expedient to use ventilation grilles, which would have an area within 0.05–0.06 m^2. In this case the greatest heat productivity of a thermosyphon at various thicknesses of an air layer is observed. This is due to the most intensive process of convective heat transfer between the moving air in the layer and the surface heated by the radiator.

Conclusions

1. An analysis of the current state of modular construction and confirmed that this area is very relevant because it has the ability to quickly transport factory-made building structures and install them on site, which reduces construction time. Modular construction accelerates the pace of construction, in the factory creates a product that is quickly mounted on sites of ready-made modules (assemblies, blocks).

2. The technology of passive use of solar energy in hybrid external constructions of a modular house with the use of thermosyphon solar collectors in order to reduce the consumption of traditional energy sources is proposed.

3. The use of thermosyphon solar panels in modular buildings increases their energy independence (autonomy) compared to traditional heat sources.

References

Dennis Holloway (2003). Passive solar house: A simple design method Method of designing heating systems for passive solar homes based on the principles of direct and indirect heating, 26. https://mensh.ru/files/passive_solar.pdf.

Development of renewable energy sources in Ukraine / Ministry of Regional Development (2017). P. 36. https://www.minregion.gov.ua/wp-content/uploads/2017/03/Rozvitok-VDE-v-Ukrai--ni.pdf.

European Commission. Nearly Zero-Energy Buildings (2014) Available online: https://ec.europa.eu/energy/ topics/energy-efficiency/energy-efficient-bu... (accessed on 25 April 2021).

Majumder, A.; Canale, L.; Mastino, C.C.; Pacitto, A.; Frattolillo, A.; Dell'Isola, M. (2021) Thermal Characterization of Recycled Materials for Building Insulation. *Energies*, 14, 35–64. https://doi.org/10.3390/en14123564.

Ulewicz, M., Zhelykh, V., Kozak, K., Furdas, Y. (2020) Application of Thermosiphon Solar Collectors for Ventilation of Premises. Lecture Notes in Civil Engineering, 2020, 47, pp. 180-187. DOI https://doi.org/10.1007/978-3-030-27011-7_23

Ulewicz, M., Zhelykh, V., Furdas, Y., Kozak, K. (2021). Assessment of the Economic Feasibility of Using Alternative Energy Sources in Ukraine. In: Blikharskyy, Z. (eds) Proceedings of EcoComfort 2020. *EcoComfort* 2020. Lecture Notes in Civil Engineering, vol. 100. Springer, Cham. https://doi.org/10.1007/978-3-030-57340-9_59.

Marza, Carmen; Corsiuc, Georgiana; Graur Ana-Maria. Study on modular houses design. *Journal of Industrial Design and Engineering Graphics*; Bucharest. Tom 14, Nr/wyd. 1, (May 2019): 75–78. ISSN 2344-4681 from http://sorging.ro/jideg/index.php/jideg/issue/view/jidegv14i1.

Huang, Chuen-huei J.; Krawczyk, R. (2007). A Choice Model of Consumer Participatory Design for Modular Houses. Predicting the Future [25th eCAADe Conference Proceedings / ISBN 978-0-9541183-6-5] Frankfurt am Main (Germany), 26–29 September 2007, 679-686 http://papers.cumincad.org/cgi-bin/works/Show?ecaade2007_026.

Miciuła, I.; Wojtaszek, H.; Bazan, M.; Janiczek, T.; Włodarczyk, B.; Kabus, J.; Kana, R. (2020). Management of the energy mix and emissivity of individual economies in the European Union as a challenge of the modern world climate. *Energies*, 13, 5191. https://doi.org/10.3390/en13195191.

Ferdous, W., Bai, Y., Ngo, T.D., Manalo, A., Mendis, P. (2019). New advancements, challenges and opportunities of multi-storey modular buildings – A state-of-the-art review. *Engineering structures*, 183, 883–893. https://doi.org/10.1016/j.engstruct.2019.01.061

Sanchez Benjamina, Rausch Christopherb, Haas Carlb (2022). Feature modeling for configurable and adaptable modular buildings. *Advanced Engineering Informatics*, Vol. 51, January 2022, 101514, https://doi.org/10.1016/j.aei.2021.101514

Shapoval, S., Shapoval, P., Zhelykh, V., ...Savchenko, O., Myroniuk, K. (2017). Ecological and energy aspects of using the combined solar collectors for low-energy houses. *Chemistry and Chemical Technology*, 11(4), 503–508. DOI: 10.23939/CHCHT11.04.503.

Zhelykh, V., Kozak, C., Savchenko, O. (2016). Using of thermosiphon solar collector in an air heating system of passive house. *Pollack Periodica*, 11(2), 125–133 . DOI: 10.1556/606.2016.11.2.11.

Patrik Jensen (2010). Configuration of Modularised Building Systems. Printed by Universitetstryckeriet, Lulea. ISBN 978-91-7439-108-4. https://www.diva-portal.org/smash/get/diva2:999331/FULLTEXT01.pdf.

George-Lucian Ionescu (2017). Passive House. *Journal of Applied Engineering Sciences*, 7(1). DOI: 10.1515/jaes-2017-0003.

Foster J., Sharpe Tim R., Sharpe A. (2016). Scottish Passive House: Insights into Environmental Conditions in Monitored Passive Houses. April 2016*, Sustainability*, 8(5):412. DOI: 10.3390/su8050412

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АЛЬТЕРНАТИВНІ СИСТЕМИ ТЕПЛОЗАБЕЗПЕЧЕННЯ МОДУЛЬНИХ БУДИНКІВ

У наш час надзвичайно актуальною залишається проблема енергоощадного будівництва. Застосування альтернативних джерел енергії для теплозабезпечення будівель і споруд є одним зі шляхів вирішення проблеми раціонального використання паливно-енергетичних ресурсів. У цій статті розглянуто ефективні методи використання сонячної енергії за допомогою термосифонних сонячних колекторів, інтегрованих у зовнішні огороджувальні конструкції модульного будинку. Результати досліджень показали, що для ефективної роботи термосифонного колектора площа вентиляційних отворів повинна бути в межах 0,005–0,06 м^2.

Питання зниження витрат на паливно-енергетичні ресурси та зменшення впливу на навколишнє середовище, а також термінів реалізації проєктів сьогодні більш ніж актуальні для будівельних компаній і знайшли відображення у сучасному “модульному будівництві”. Тому Україні потрібно було б звернути увагу на цю сучасну будівельну систему як один зі способів вирішення проблем нестачі нових та розселення старих житлових площ.

Важливим питанням під час розроблення модульних будинків залишається проблема підтримання теплового стану в приміщеннях. Потрібно враховувати можливість автономного забезпечення таких об’єктів енергоресурсами. Це можливо у разі використання альтернативних видів енергії, таких як сонячна та геотермальна енергія, а за можливості – енергія вітру та біогазу. Отже, нині технології модульного будівництва потребують комплексного підходу до вирішення питань енергоощадності та забезпечення необхідних параметрів мікроклімату в таких будинках.

Ключові слова: термосифонний сонячний колектор; модульний будинок; сонячна енергія; параметри мікроклімату; інфрачервоне випромінювання; альтернативна енергія.