Theory and Building Practice

Vol. 5, No. 1, 2023

https://doi.org/10.23939/jtbp2023.01.056

Petro Novosad, Uliana Marushchak, Oksana Pozniak

EFFECTIVE WALL STRUCTURES WITH USE OF FLAX STRAW CONCRETE

Lviv Polytechnic National University,
Department of Building Production,
uliana.d.marushchak@lpnu.ua

The modern building technologies are technologies of green construction, near zero-energy and active buildings with bioclimatic design, optimized energy consumption and CO_2 emissions. Prospective enclosing structures of such buildings are structures using available, low cost, and environmentally friendly materials based on plant raw materials. In this paper the evaluation of technical solutions of wall enclosing structures using flax concrete based on lime binder with a density of 300–350 kg/m^3 was carried out, taking into account their heating and cooling loads in residential buildings. It is shown that the provision of the necessary indicators of the external walls of energy-efficient buildings is achieved by using multilayer structures with a heat-insulating layer of flax straw concrete or a single-layer structures made from flax straw concrete in frame construction technology.

Key words: flax straw concrete, wall structure, thermal insulation, energy efficient building, green construction, resistance to heat transfer, heat transfer.

Introduction

The building sector is one of the most energy-intensive, accounting for more than one-third of all final energy and half of total electricity consumption worldwide (Attia et al., 2022). The construction and operation of buildings, as well as the production of building materials, cause up to 40 % of all pollutant emissions and about one third of soot emissions (Mostafavi, Tahsildoost, & Zomorodian, 2021). According to forecasts, population growth, increasing requirements for the level of comfort and service in buildings, increasing the time spent inside buildings will lead to further growth in energy demand in the future. Thus, currently, energy awareness in building design is crucial.

In Ukraine, energy-saving technologies began to be more intensively implemented in construction practice after the adoption of the law “On Energy Efficiency of Buildings” dated October 17, 2017. In accordance with the provisions of this law, a new version of DBN B.2.6-31:2021 “Thermal insulation and energy efficiency of buildings” was approved. These documents envisage strengthening the requirements for the reduced heat transfer resistance of the enclosing structures of buildings, as well as the classification of buildings by energy efficiency. However, the energy consumption of existing buildings in Ukraine yet is more in 2.5–3.0 times compered to EU countries with the same climatic conditions (Sanytsky, Marushchak, Secret & Wojcikiewiez, 2014).

The invasion of russia is making adjustments to the transformation of buildings in Ukraine into energy-independent ones. By the end of 2022 143,800 houses destroyed as a result of military actions were recorded in Ukraine. War is the worst tragedy. But for all that, it’s also a chance to update and improve. On July 5, 2022, representatives of more than 40 countries and about 20 international organizations at the International Conference in Lugano, Switzerland approved the Declaration and approved seven principles for the restoration of Ukraine, especially the energy and building sectors (Lugano Declaration, 2022). The recovery process should take place according to the requirements of sustainable development until 2030 and the Paris Agreement, based on the principle of “build back better”. An increase in construction resources for the future reconstruction of Ukraine may lead to an increase in energy consumption, as well as pollution and emissions, which determines the implementation of energy efficiency and resource conservation measures during construction (Santamouris & Vasilakopoulou, 2021).

Since energy consumption has recently been considered inextricably linked with greenhouse gas emissions and the impact of construction activities on the environment is becoming more and more evident, the strategy of green construction is increasingly being implemented (Norouzi & Nasiri, 2021).

Green construction, green buildings are an advanced practice of construction and operation of buildings, the purpose of which is to reduce the level of consumption of energy and material resources during the whole life cycle of the existence of a building, from selection of site to design, production of building materials, construction, operation, repair and destruction, with subsequent use of the generated waste (Chi, B., Lu, W., Ye, M., Bao, Z., & Zhang, X., 2020). This plan considers Net zero carbon building, including embodied carbon – an energy-efficient building that produces or purchases sufficient carbon-free renewable energy on site to meet the annual energy consumption of the building, as well as throughout its life cycle (i. e. offsets the building's carbon footprint from energy consumption, building structures and materials) (Keltsch, Lang, Aue, 2017; Kozak-Jagieła, Kusak, Klich, & Mojkowska-Gawełczyk, 2020; Sanytsky, Sekret, & Wojcikiewiez, 2012). An active house should be characterized by low energy consumption, low impact on the environment, as well as the necessary living conditions.

Walls play a decisive role, when designing energy-efficient buildings. The walls bear the weight, but the walls also perform the function of heat insulation and sound insulation. They provide the optimal thermal and moisture regime, as well as the mechanical characteristics and durability of the building. (Antonelli, Erba, & Azambuja, 2020; Marushchak, Pozniak, 2022; Marushchak, Pozniak, & Mazurak, 2023). However, the production process of wall materials (ceramic wall materials, concrete blocks, aerated concrete blocks) requires a lot of energy. Increased energy consumption is also associated with the production of traditional thermal insulation materials, such as mineral wool, glass wool, polystyrene foam (Perry, 2019). The use of a significant amount of energy in the production of traditional wall and thermal insulation materials leads to the formation of a large amount of greenhouse gases, in particular carbon dioxide. Since building standards require an ever higher level of thermal insulation, the impact of materials used for thermal insulation on the environment cannot be underestimated.

Green building standards promote the development of recyclable materials and materials to improve indoor air (Wang, H. et al., 2018). Thus, environmentally friendly building materials should create minimal emissions and waste, consume less energy, and be useful to humans while maintaining high quality (Pedroso, Brito, & Silvestre, 2019). Green construction material is a kind of building material which needs to meet the following points: the use of clean production technology; no or less use of natural resources and energy; a large amount of use of industrial, agricultural, or municipal solid waste production with the features of free-pollution, recyclability, environmental protection, and human health (Torres-Rivas, et al., 2021).

One idea of green building is to replace some building materials with plant-based materials to reduce CO_2 levels. Cellulosic materials based on straw, flax waste, hemp, and wood are the most environmentally friendly raw materials used in construction (Marques, Tadeu, Almeida, António, & Brito, 2020; Novosad & Pozniak, 2021; Babenko, Estokova, Unčik & Savytskyi, 2022; Hajj Obeid, M. et al., 2022). During growth, the plant absorbs carbon dioxide and keeps it in the material during operation. On the one hand, the use of plant materials will help to solve the problems of disposal of agricultural waste, on the other – to obtain inexpensive and effective thermal insulation materials. The advantages of plant raw materials include availability, quick recovery, low cost, environmental friendliness and low thermal conductivity, as well as the possibility of using both organic and inorganic binders. The advantages of flax include reducing the level of radiation, weakening gamma radiation, electromagnetic waves from household and industrial equipment, which will ensure healthy living conditions for residents in buildings made of flax concrete. It is most rational to use plant raw materials of flax straw, rye, as wall blocks protected by a clay or sand-cement plaster layer on a reinforcing mesh, or as a thermal insulation material, or wall material in frame low-rise construction Garikapati, & Sadeghian, 2020; Kisilewicz, Fedorczak-Cisak, & Barkanyi, 2019).

The purpose of this study is to analyse the use of flax straw concrete for external wall structures of energy-efficient buildings.

Materials and Methods

The flax straw concrete based lime binder was used for analyse indicators of energy efficiency of wall enclosing structures of low-rise buildings. Flax straw is the lignified parts of flax stalks, crushed during primary processing (Fig. 1, *a*). It accounts for 60–70 % of the mass of processed flax stalks. For the preparation of flax concrete, flax straw was used as an organic filler (Fig. 1, *b*).

Flax waste is particles of 10–20 mm long and of 0.1–1.5 mm thick, with a bulk density of approximately 110–130 kg/m^3. A feature of flax fiber is its high porosity (approximately 70–75 %). The oven-dry density of flax straw concrete is 300–350 kg/m^3. The calculated value of the thermal conductivity coefficient is 0.07–0.08 W/(m·K) and water vapor permeability – 0.12 mg/(m·h·Pa).

a *b*

Fig. 1. Flax straw and flax straw concrete

There are various variants for using flax straw concrete for energy-efficient wall structures:

1) a multi-layered wall with a structural layer and a layer of insulation (thermally heterogeneous enclosing structure) – variant 1;

2) a wall in which the functions of insulation and structural layer are combined (thermotechnically uniform enclosing structure) – variant 2.

The choice of a specific variant depends on the climatic conditions and the constructive decision adopted at the construction design stage.

The wall structure made from flax straw concrete were compared according to thermal criteria – resistance to heat transfer and heat transfer coefficient. The thermal criteria for heterogeneous structures as well as the moisture regime of both variants of wall were calculated according with the current regulations of Ukraine for the external conditions of Lviv region used program Audytor OZC. The heat transfer by transmission per 1 m^2 for both variants of wall during the heating season and solar heat gains per 1 m^2 of walls of southern orientation during cooling season were calculated. The cooling season includes three summer months. Indoor air parameters were taken for residential buildings.

Results and discussions

The wall construction of variant 1 was used in the thermal modernization of the walls of a residential one-story building in the village of Zashkiv, Lviv region (Fig. 2). The load-bearing wall of the building is made of ceramic bricks with a thickness of 0.38 m. To insulate the wall, vertical wooden beams were installed at intervals of about one meter. Then the formwork is installed and flax straw concrete is placed into it and compacted (Fig. 2, *a*). Externally, flax straw concrete is protected with lime-sand mortar with a thickness of 0.015 m (Fig. 2, *b*).

a

b

Fig. 2. Installation of thermal insulation with flax straw concrete

Variant 2 of the wall structure was used in the construction of a frame house in the village of Krekhiv, Lviv region (Fig. 3, *a*). In this case, load-bearing wooden beams are installed, then formwork is installed, flax straw concrete is placed into it and compacted (Fig. 3, *b*). A flax straw concrete is protected from the outside and from the inside with a lime-sand mortar with a thickness of 0.015 m.

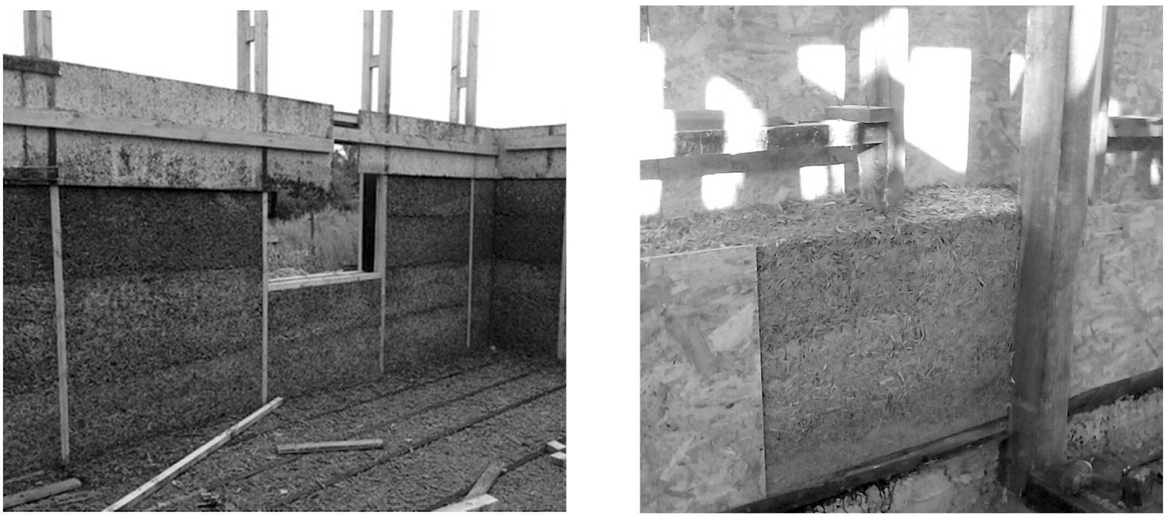
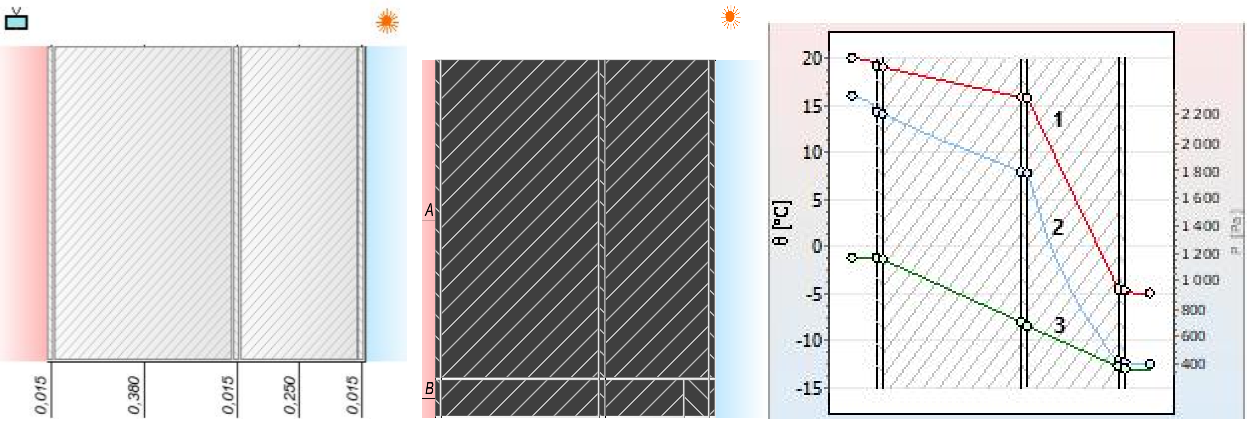


Fig. 3. Wall structures of a frame house with flax straw concrete

The decision of the problem of effective thermal insulation of external walls consists in choosing the optimal thermal insulation material and justifying the economically feasible thickness of the thermal insulation material (Voznyak, Yurkevych, Sukholova, Dovbush & Kasynets, 2020). A partial requirement energy effectiveness for wall structures is the resistance to heat transfer and heat transfer coefficient. The installation of thermal insulation from flax concrete requires the installation of guide wooden beams 0.1 m wide and 0.06 m thick approximately one meter apart (Fig. 2), which determines the heterogeneity of the wall structure.

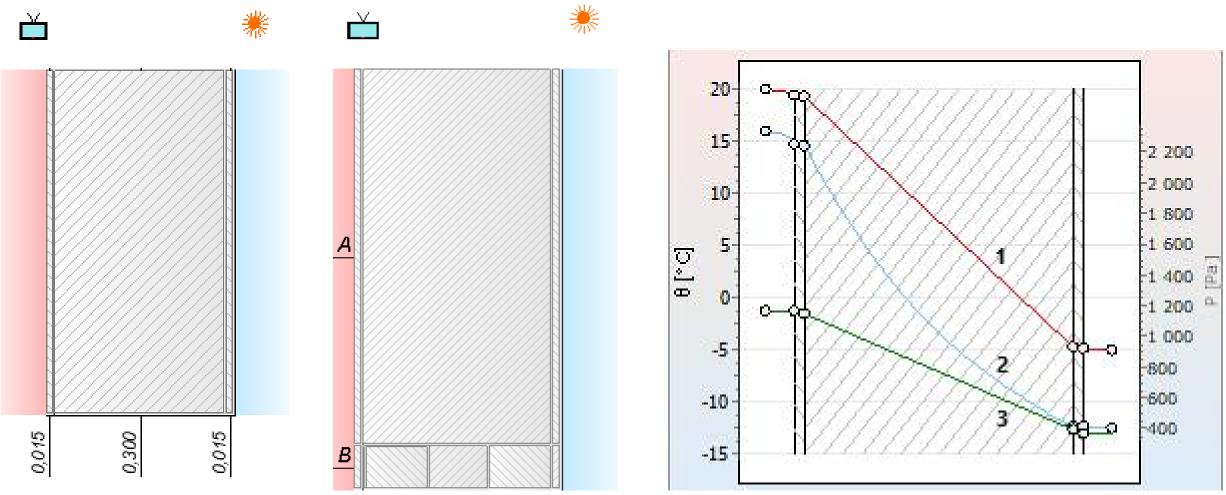
Calculation of the thermal parameters of a multi-layer enclosing wall structure using a heat-insulating material based on flax straw concrete was carried out for a homogeneous field of the structure (Fig. 4, *a*) and a non-homogeneous field including wooden beams (Fig. 4, *b*). It is shown that with a thickness of the heat-insulating layer of reinforced concrete of 0.25 m, the standard heat transfer resistance of 4.109 m^2·K/W is provided for a homogeneous zone, taking into account the heterogeneity of the structure, the heat transfer resistance decreases to 4.053 m^2·K/W. The given heat transfer resistance of such structure meets the requirements of the current standard. The total thickness of the structure is 0.675 m. The calculation of the heat-humidity regime of the enclosing structure indicates the absence of condensation of water vapor (Fig. 4, *c*).



a *b* *c*

Fig. 4. Scheme of homogeneous (a) and non-homogeneous (b) wall structure insulated with flax straw concrete; distribution of water vapour pressure in the wall structure (c): 1 – temperature; 2 – water saturation pressure; 3 – partial pressure

The calculation of the heat transfer resistance of the enclosing wall structure using a reinforced concrete base for a uniform field of the structure (Fig. 5, *a*) showed that with a thickness of the flax straw concrete layer of 0.3 m provides a standard heat transfer resistance of 4.203 m^2·K/W, taking into account the heterogeneity of the structure, the heat transfer resistance decreases to 4.03 m^2·K/W (Fig. 5, *b*). The heat transfer resistance of this designed structure meets the requirements of the current standard. The total thickness of the structure is 0.33 m. The calculation of the heat-moisture regime of the enclosing structure indicates the absence of condensation of water vapor (Fig. 5, *c*).



a *b* *c*

Fig. 5. Scheme of homogeneous (a) and non-homogeneous (b) wall structure made of flax straw concrete; distribution of water vapour pressure in the wall structure (c): 1 – temperature; 2 – water saturation pressure; 3 – partial pressure

To assess the energy efficiency of buildings, a complex indicator is used, which takes into account the need of energy for heating and cooling. One of the main components of the energy balance of buildings during the heating season is heat loss through wall-enclosing structures. To ensure comfortable indoor conditions in the summer, it is necessary to use air conditioning devices, which leads to increased consumption of electrical energy. Excessive overheating primarily affects southern facades. Thus, heat loss during the heating period and heat gain during the cooling period through 1 m^2 of wall structures of both variants were calculated (Fig. 6).

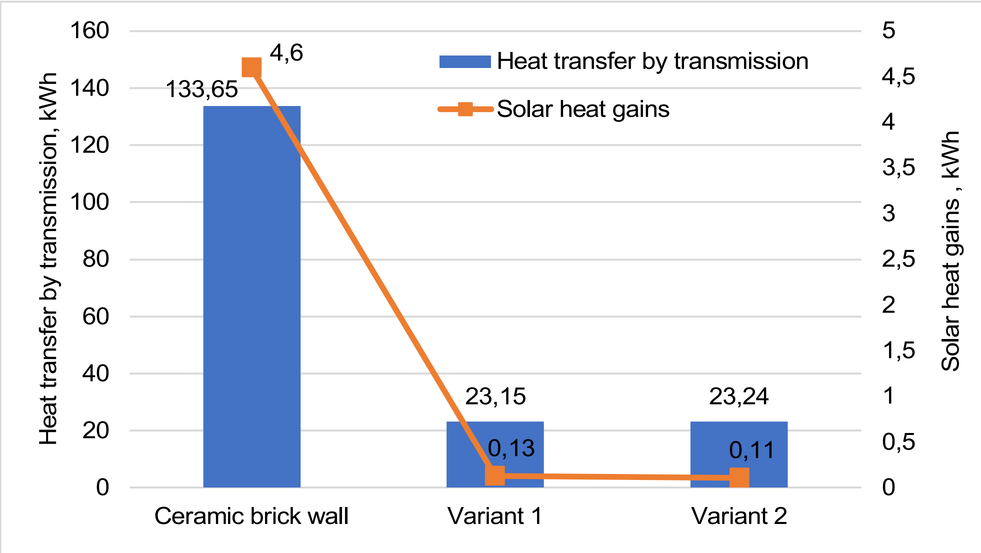


Fig. 6. Heat transfer by transmission and solar heat gains of the external wall

The walls of both variants are characterized by similar values of resistance and heat transfer coefficient, so the amount of heat lost through the enclosing structures does not differ significantly. Thus, for wall structure of variant 1 the heat losses are 23.15 kWh per 1 m^2 of wall, and for wall of variant 2–23.24 kWh per 1 m^2 of wall. This is 5.8 times less compared to an uninsulated wall made of traditional ceramic bricks. Estimated values of solar heat inflows through 1 m^2 of south-facing exterior walls during the cooling period are 0.11–0.13 kWh, while for an uninsulated ceramic brick wall – 4.6 kWh. In addition, the internal thermal inertia of the building is taken into account when calculating energy consumption for heating and cooling. This value determines what proportion of the heat entering the building is absorbed by the enclosing structures. At the same time, the internal heat capacity of the walls of variant 1 is 3.2 times higher compared to the walls of variant 2, which significantly affects the overall energy consumption of the house and the energy efficiency class.

Conclusions

1. The integration of energy efficiency and environmental factors in the design and construction of new buildings, thermal modernization of existing buildings is important for the sustainable recovery of Ukraine after the victory, and will also contribute to increasing the economic, energy and environmental security of the country in the future.

2. The design of efficient wall structures based on plant materials with a low carbon footprint will allow the disposal of agricultural waste, minimize the need for energy to achieve internal thermal comfort conditions, and ensure a healthy microclimate in buildings. The research results showed the possibility of using flax concrete for energy-efficient wall structures of low-rise buildings.

3. The flax concrete can be used as a thermal insulation layer to insulate the walls of existing buildings, as well as a wall material in frame construction. Such wall structures will meet the requirements for

heat transfer resistance when the thickness of the thermal insulation layer is more than 0.25 m, the wall thickness of the frame house is more than 0.3 m.

4. High heat transfer resistance and high thermal inertia of walls using flax straw concrete lead to a decrease in heat transfer by transmission during the heating season (23.15–23.24 kWh/m^2·wall·year) and solar heat gains in cooling period (0.11–0.13 kWh/m^2 wall·year), as a result of which energy consumption for heating and cooling is reduced.

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П. В. Новосад, У. Д. Марущак, О. Р. Позняк
Національний університет "Львівська політехніка"
кафедра будівельного виробництва

ЕФЕКТИВНІ СТІНОВІ КОНСТРУКЦІЇ З ВИКОРИСТАННЯМ БЕТОНУ НА ОСНОВІ КОСТРИ ЛЬОНУ

Будівельні технології, які відповідають сучасним вимогам енергоефективності та екології, – це технології зеленого будівництва, близько нуль-енергетичних будівель з біокліматичним дизайном та оптимізованим енергоспоживанням. Виробництво будівельних матеріалів, зокрема теплоізоляційних, частка яких зростає у енергоефективному будівництві, пов'язане із значним енергоспоживанням та викидами вуглекислого газу. Згідно з сучасними тенденціями, перспективними огороджувальними конструкціями в зелених будівлях є конструкції з використанням матеріалів з низьким впливом на довкілля на основі природної сировини та відходів. Проведено оцінку технічних рішень стінових огороджувальних конструкцій житлових індивідуальних будинків із використанням легкого теплоізоляційного бетону на основі костри льону та вапняного в'яжучого із середньою густиною 300–350 кг/м^3 для періоду опалювання та охолодження. Показано, що забезпечення необхідних показників зовнішніх стін енергоефективних будівель досягається використанням багатошарових конструкцій із теплоізоляційним шаром костробетону або одношарових стінових конструкцій з костробетону за каркасною технологією будівництва. Такі стінові конструкції відповідають вимогам за приведеним опором теплопередачі за товщини теплоізоляційного шару з легкого костробетону більше ніж 0,25 м та товщини стіни каркасного будинку з теплоізоляційного бетону більше ніж 0,3 м. Високий опір теплопередачі та висока теплова інерційність стін із застосуванням костробетону призводять до зниження втрат теплоти в опалювальний період (23,15–23,24 кВт·год/(м^2 стіни·рік)) та надходження сонячного тепла в період охолодження (0,11–0,13 кВт·год/(м^2·стіни·рік)), унаслідок чого зменшується споживання енергії на опалення та охолодження будівлі.

Ключові слова: костробетон, стінова конструкція, теплоізоляція, енергоефективна будівля, зелене будівництво, опір теплопередачі, тепловтрати.