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Uliana Marushchak and Oksana Pozniak

ANALYSIS OF WALL MATERIALS ACCORDING TO THERMAL PARAMETERS

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

Based on the analysis of energy consumption and carbon dioxide emissions of the construction industry, it is stated that the reduction of energy consumption in Ukraine is achieved through termomodernization of the existing building stock and build new buildings, which meet energy efficiency requirements. Comparison of thermal parameters of different wall materials are given. It is shown that multilayer wall constructions must be used to ensure the necessary indicators of external walls of energy efficient buildings. The use of effective wall materials allows to ensure compliance with the given temperature difference to regulatory documents and reducing of heat transfer by transmission during the heating season, solar heat gains during cooling season.

Key words: wall material; energy efficiency; energy efficient building; thermal parameter; resistance to heat transfer; heat transfer by transmission; solar heat gains; building stock.

Introduction

Currently, buildings sector remains the most energy-intensive sector of the world economy. Energy consumption is growing rapidly due to population growth and urbanization. In the operational phase of building a significant part of energy (60–80 %) is used for heating, air conditioning, ventilation and artificial lighting. The buildings sector has a very large carbon footprint due to the significant share of fossil fuel use. About 9 % of global CO_2 emissions result from the use of fossil fuels in buildings for heating, cooking and hot water (Attia et al., 2022; Mostafavi, Tahsildoost, & Zomorodian, 2021). This identifies the need for a tripartite strategy to intensively reduce energy demand in construction, decarbonise it and implement strategies for building materials that reduce carbon emissions over the life cycle (Torres-Rivas et al., 2021). These principles are the base of philosophy of green building or sustainable building, goal of which is the maximum reduce the overall impact of the build on human health and the natural environment (Chi, Lu, Ye, Bao & Zhang, 2020).

The energy consumption to maintain 1 m^2 of floor area in Ukraine is more in 2.5–3.0 times compered to EU countries with the same climatic conditions (Sanytsky, Marushchak, Moskvytyn, Secret & Wojcikiewiez, 2012). Deep energy modernization is achieved through the construction of new efficient buildings and thermal modernization of existing housing to ensure high standards of energy efficiency. In order to promote the energy efficiency of buildings and achieve the national goal of energy efficiency in terms of reducing the specific energy consumption of buildings, the Law of Ukraine "On Energy Efficiency of Buildings" was adopted in 2017.

An energy efficient building is designed so that provide the necessary functions, comfort and convenience while using as little energy as possible. The whole process of building design must be strictly subordinated to achieve the specified energy efficiency of the object. The energy efficiency of a building depends on the following factors: quality of materials and construction solutions of external structures; technical installations of the building, such as sources of production, distribution and use of energy; the way the building is used and its resources (Zhelykh, Kasynets, Myroniuk, Marushchak & Gulai, 2021; Marushchak, Pozniak, Soltysik & Prots, 2019).

Determining decisions to achieve energy efficiency of the building are the decision on its external envelope structures, which provide bear ability and act as sound and heat insulation, provide optimal heat and moisture regime, as well as mechanical characteristics and durability of the building. At the same time, considerable attention is paid to external wall structures, taking into account their large area (Sadeghi & Mohandes, 2013).

The existing building stock of Ukraine is 1014.8 million m^2. About 40 % of buildings were built more than 50 years ago, and 90 % of houses were built before 1990. 47 % of buildings built by industrial methods in the 60s of last century on the projects of the first mass series are panel buildings, 50 % – buildings with brick walls, 3 % – houses were built using prefabricated large-block elements (Ageeva, Krivelyov & Kafiev, 2021). Current construction trends show that the developer is interested not only in the structural elements of house, but also in efficient construction technologies. The modern market of materials is represented by great variety of products to increase the efficiency of construction, as trends in building construction take into account the increased requirements for comfort and energy saving. First of all, the manufacturers focused on the energy efficiency of design solutions and materials used.

In Europe 250×120×65 mm bricks replaced by large-format 440×245×215 mm blocks and other formats of 10–13 bricks in one block, which is due to the increased thermal insulation properties of the block and resource savings of technology. At the same time, in Ukraine bricks are most often used for building walls – 48.3 % of cases, due to the increased strength and durability of this building material. 21 % of buildings use wood. In 18.7 % – blocks (aerated concrete, polystyrene concrete and others). This technology has advantages in environmental friendliness, energy efficiency and has a lower cost of construction compared to other materials. Natural stone (shell rock, tuff) or monolith has the lowest demand for wall construction – 7.8 % of cases.

When constructing multi-storey buildings, developers prefer bricks and ceramic blocks. Thus, in the capital's developers for the construction of residential complexes of comfort and business class in 50 % of cases use ceramic bricks and 26 % – ceramic blocks. The capital's developers rarely use the gas block (16 % of business class buildings), although it is faster to build from it. In 8 % of cases, developers combine ceramic bricks or blocks for the construction of external walls with gas blocks for internal walls.

It should be noted that in Ukraine in recent years the demand for single-family house is growing, the construction of cottages, townhouses and others is intensifying. The share of single-family buildings exceeds 50 % in the structure of building, which corresponds to global trends in developed countries. According to the State statistic service of Ukraine, the area of one-apartment buildings commissioned in 2020 will reach 3 million m^2 and 2.7 million m^2 of apartment buildings. The range of wall materials is much wider for single-family houses, as it can be used materials with lower strength and increased thermal insulation. Expanded clay, foam concrete, aerated concrete, polystyrene concrete, arbolite, adobe, straw blocks are most often used for individual buildings (Pozniak, Melnyk, Margal & Novosad, 2021).

The modern market of wall building materials offers a wide choice, but to leave future homeowners in front of the need for a difficult choice among them. Predominant development of support for such technologies that reduce the cost, material consumption, complexity of production of modern efficient building materials. The use of green materials as the most critical renewable materials in all aspects of human existence appears to be the most effective way to optimize resource use and reduce the environmental impact associated with social activities (Norouzi & Nasiri, 2021). Currently, cost-effective construction technologies that meet modern requirements for energy saving and ecology are envelope structures using local materials. In areas where wood and brick are expensive building materials, it is most rational to use blocks of flax straw, rye, protected by a clay or sand-cement plaster layer on the reinforcing mesh (Marques, Tadeu, Almeida, António & Brito, 2020; Novosad & Pozniak, 2021; Pedroso, Brito & Silvestre, 2019). Recycled wood is one of the materials with great potential for recycling (Wang at al., 2018). Arbolite blocks and OSB for SIP-panels are made based it.

The aim of this study is to analyse traditional and effective wall materials according to thermal parameters to find constructive solutions of external wall constructions of energy efficient buildings.

Materials and Methods

The wall materials from which the main building stock is built are selected for comparison: ceramic bricks (solid and hollow), sand lime brick, expanded clay concrete panels, as well as block of porous ceramics, aerated concrete blocks, arbolite blocks. Calculated characteristics of wall materials in different operating conditions (A – dry conditions, B – normal and wet) are given in Table 1. Thermal indicators for operating conditions A are used for calculations indicators during the cooling season.

Table 1

Calculated characteristics of the wall material

No	Wall material	Thickness, mm	Density, ρ, kg/m^3	Thermal conductivity in operating conditions, λ, W/(m K)		Heat absorption coefficient, s, W/(m^2·K) condition A
				А	Б	
1	Solid ceramic brick	380–510	1800	0.70	0.81	9.20
2	Hollow ceramic brick	380–510	1400	0.58	0.64	7.91
3	Sand lime brick	380–510	1800	0.76	0.87	9.77
4	Reinforced concrete wall panel	300–350	1200	0.52	0.58	6.77
5	Block of porous ceramics	380–440	750	0.20	0.26	5.06
6	Aerated concrete block	400	600	0.16	0.18	2.65
7	Arbolite block	400	600	0.18	0.23	4.63

Wall made from these materials were compared according to thermal criteria - resistance to heat transfer and heat transfer coefficient, given temperature difference, minimum temperature on the wall surface, heat transfer by transmission per 1 m^2 of wall during the heating season, heat resistance during cooling season and solar heat gains per 1 m^2 of walls of northern and southern orientation. All characteristics were calculated in accordance with the current regulations of Ukraine for the external conditions of Lviv region. Indoor air parameters were taken for residential buildings.

Results and discussions

The main indicators of wall structures are the resistance to heat transfer and heat transfer coefficient, which determine the energy efficiency of buildings. According to Fig. 1 resistance to heat transfer of single-layer walls of obsolete residential buildings made from ceramic or sand lime brick and reinforced concrete expanded clay concrete panels is 0.63–0.99 (m^2·K)/W. Regulatory requirements for heat transfer resistance of wall of buildings, which were built in the 60–80s of last century, are lower in 3–5 times than the minimum allowable values in the current DBN B.2.6-31:2016. Implementation of the national plan to increase the number of nearly zero-energy buildings in accordance with the Law "On energy efficiency of buildings" requires an immediate increase in regulatory requirements for thermal resistance of structures. In the draft of the new DBN B.2.6-31:XX normative indicators of thermal resistance will be increased by 21–25 %, which will further deepen the problem of non-compliance of external constructions of the existing building stock with energy performance requirements and requires urgent and radical thermal modernization (Kisilewicz, Fedorczak-Cisak, & Barkanyi, 2019; Sanytsky, Sekret & Wojcikiewiez, 2012).

First of all it concerns thermal insulation of external walls which is effective in the thermal relation and is characterized by short payback period. Therefore, the decision of a problem of thermal insulation of external walls is carried out in two stages: a choice of optimum heat-insulating material and a substantiation of economically expedient thickness of heat-insulating material (Voznyak, Yurkevych, Sukholova, Dovbush & Kasynets, 2020).

To ensure the minimum requirements for energy efficiency, walls made from traditional wall materials of the existing building stock require the use of facade thermal insulation systems (multilayer walls). The thickness of the thermal insulation layer with a coefficient of thermal conductivity (0.05 W/(m·K)) is 12–14 cm. While the use of effective wall materials (arbolite, aerated concrete, block of porous ceramics) can provide the minimum requirements using 5–8 cm of insulation material. Given the increase in resistance requirements, the thickness of the insulation should be increased to 8–17 cm. It should be noted that global trends suggest a decrease in the density of aerated concrete while maintaining its strength. Thus, "Aeroc" company has mastered the production of autoclaved aerated concrete class D300 with a compressive strength class of C2.0 and a thermal conductivity of 0.09 W/(m·K) (Serdiuk, Franishina, Serdiuk & Rudchenko, 2021). Use of such blocks allows to realize construction of single-layer walls with resistance of heat transfer of 4.4 m^2K/W.

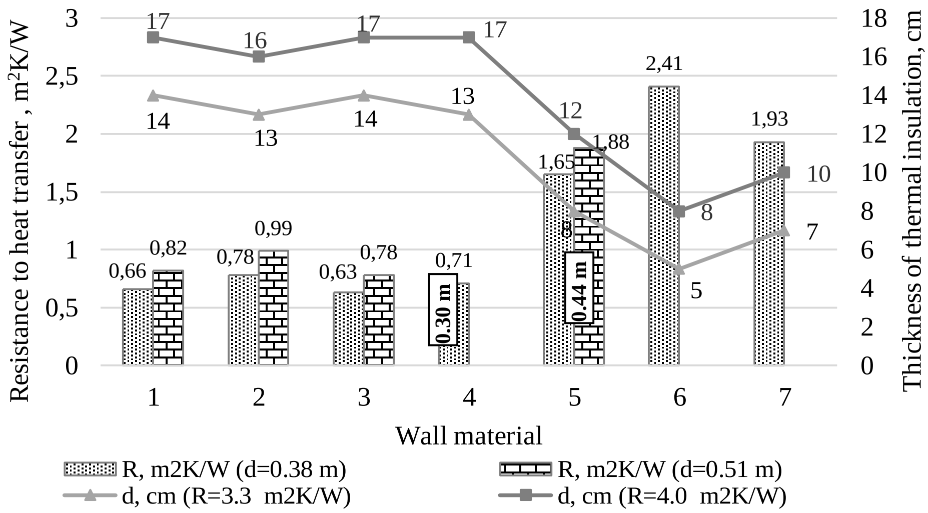

Fig. 1. Resistance to heat transfer and thickness of thermal insulation of wall
**Designation of wall material in fig. 1–3 according to table 1*

The internal temperature of the external walls determines their humidity and favourable conditions of the internal microclimate. The increase of the temperature difference between the wall and the indoor air creates the conditions for the intense movement of air, which is perceived by man as a draught. The temperature difference for a wall surface with a glazing coefficient of less than 0.18 of ceramic and sand lime bricks, expanded concrete panel is 4.9–7.7 ºC (Fig. 2). Indicators of the given difference of temperatures (Fig. 2) and heat transfer by transmission (Fig. 3) are calculated for smaller thickness of the walls given in Table 1.

The results of the calculations indicate that the walls made from such materials do not meet the sanitary requirements. The calculation of the minimum temperature for the surface of the walls from the considered showed that it exceeds the dew point for residential buildings (10.7 ºC) and the absence of condensation on them. At the same time, in the places of thermal bridges the temperature of the inner surface can decrease by 4–6 ºC, which causes condensation in these places.

Heat transfer by transmission per 1 m^2 external walls during the heating season is one of the determining factors in the energy balance of the building and its energy efficiency. The walls made from solid ceramic and sand lime brick with a thickness of 380 mm are characterized by the largest value of specific heat transfer – 133.88 kWh, as well as the walls of prefabricated buildings – 118.359 kWh. Insulation of such walls will have a significant energy and economic effect. Heat transfer by transmission per 1 m^2 external walls from effective materials is 2.6–3.8 times less.

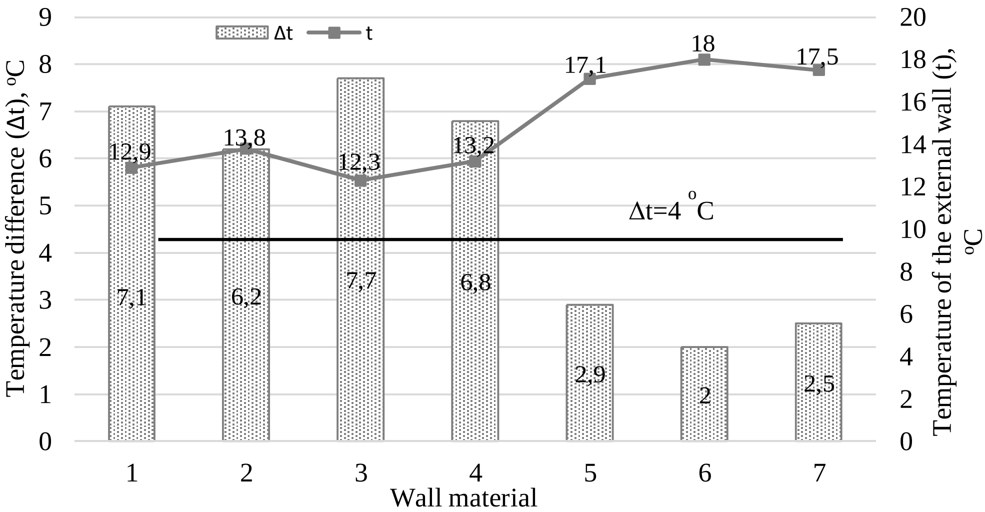

Fig. 2. Given difference of temperature and temperature of internal surface of wall

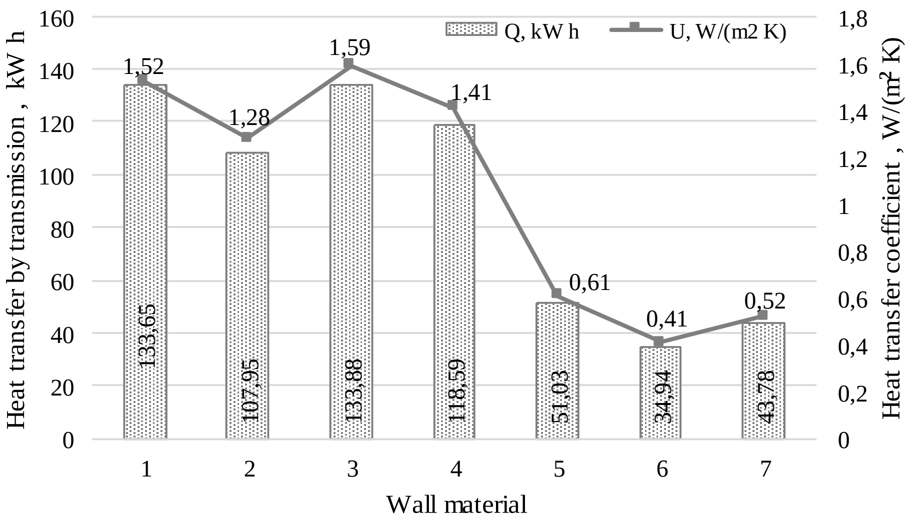

Fig. 3. Heat transfer by transmission and the heat transfer coefficient of the external wall

The excess solar heat gains through the external envelope in summer cause thermal discomfort and negatively affect the quality of life of the building's occupants. Recently, there has been a rapid increasing end use of energy in buildings for cooling, which stimulates the growth of demand of electricity in the building sector. These problems can be minimized by using wall materials to achieve the condition of internal thermal comfort in buildings (Antonelli, Erba & Azambuja, 2020).

The results of calculations of the amplitude of fluctuations of the temperature of the inner surface of envelope structures $A\tau_{in}$ show that the increase in thermal inertia of wall structures with low thermal conductivity causes an increase in their heat resistance in summer (Table 2).

Although heat resistance for all considered structures does not exceed 2.5 ºC and meets the requirements of standards. The wall construction from arbolite block is characterized by the smallest amplitude of temperature fluctuations $A\tau_{in}$ = 0.008 ºC, which indicates high heat resistance of products based on wood, straw due to the high ability to accumulate heat. The highly heat-conducting materials ceramic and silicate bricks and expanded clay concrete with low thermal resistance and heat absorption coefficient are characterized by lower indicators of heat resistance – 0.33–0.42 ºC for bricks and 0.8 ºC for expanded clay concrete panel.

Table 2

Thermal characteristics of wall structures during cooling season

No	Wall material	Thickness, mm	Thermal resistance, R, m^{2}K/W	Thermal inertia, D	$A\tau_{in}$, ºC	U, W/(m^{2}K)	Solar heat gains, kWh	
							North	South
1	Solid ceramic brick	380	0.54	5.37	0.41	1.37	3.45	7.22
2	Hollow ceramic brick	380	0.66	5.56	0.33	1.18	3.00	6.24
3	Sand lime brick	380	1.90	9.99	0.012	0.48	1.14	2.39
4	Reinforced concrete wall panel	380	0.50	5.27	0.42	1.45	3.65	7.62
5	Block of porous ceramics	300	0.58	4.29	0.80	1.30	3.26	6.81
6	Aerated concrete block	400	2.50	7.01	0.07	0.37	0.98	2.03
7	Arbolite block	400	2.22	10.67	0.008	0.45	1.17	2.43

The calculated values of solar heat gains per1 m^2 of external walls indicate that effective materials for reducing energy consumption for cooling are aerated concrete blocks, blocks of porous ceramic and arbolite. The solar heat gains per such walls of southern orientation is 2.03–2.43 kWh, which is 3.0–3.5 times less than a brick or expanded clay concrete panel.

Conclusions

Significant reduction of material and energy resources in the construction sector is achieved through the implementation of the concept of energy efficient construction both in the construction of new buildings and in the thermal modernization of existing housing. As the basic structure of a building, wall materials could create huge perspectives in a greenway. The resistance to heat transfer of single-layer walls of obsolete residential buildings is lower in 3–5 times than the minimum allowable values. The minimum thickness of the thermal insulation layer in this case is 12–14 cm. Low resistance to heat transfer and low thermal inertia of brick walls and expanded clay concrete panel causes increased heat transfer by transmission during the heating season (118.36–133.88 kWh) and solar heat gains in summer (2.03–2.43 kWh), which causes growing energy consumption for heating and cooling. Effective materials to reduce energy consumption for cooling are aerated concrete, ceramic and arbolite blocks. The magnitude of solar heat gains through external walls made of such materials is 2.03–2.43 kWh, which is less in 3.0–3.5 times compared to brick or wall panel.

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У. Д. Марущак, О. Р. Позняк
Національний університет “Львівська політехніка”,
кафедра будівельного виробництва

**АНАЛІЗ СТІНОВИХ МАТЕРІАЛІВ
ЗА ТЕПЛОТЕХНІЧНИМИ ПАРАМЕТРАМИ**

Зменшення енергоспоживання у будівельному секторі України пов’язане з необхідністю термомодернізації житлового фонду і будівництвом нового житла, що відповідає вимогам енергоефективності. Проаналізовано структуру стінових матеріалів, які використовують в Україні під час зведення багатоповерхових та індивідуальних будівель, та стінових матеріалів будівель, споруджених у 60-ті роки минулого століття. Згідно із сучасними тенденціями зеленого будівництва, перевагу надають матеріалам із низьким впливом на довкілля. Наведено порівняння теплотехнічних показників найпоширеніших стінових матеріалів. Показано, що для забезпечення необхідних показників опорів теплопередачі зовнішніх стін енергоефективних будівель необхідно застосовувати системи фасадної теплоізоляції. Насамперед це стосується стінових конструкцій наявного житлового фонду, опір теплопередачі яких у 3–5 рази нижчий, ніж нормативний. Використання ефективних стінових матеріалів у одношаровому виконанні дає змогу забезпечити відповідність приведеної різниці температур нормативним документам. Водночас цей показник для кладки із керамічної та силікатної цегли, керамзитобетонної панелі міститься у межах 4,9–7,7 ºС та не задовольняє сангігієнічних вимог. Низький опір теплопередачі та низька теплова інерція стін із цегли та стінової керамзитобетонної панелі спричиняють підвищені показники питомих тепловтрат за опалювальний період (118,36–133,88 кВт·год) та питомих теплонадходжень у літній період (2,03–2,43 кВт·год), що зумовлює зростання потреби на опалення та охолодження, водночас використання ефективних стінових матеріалів відповідає принципам енерго- та ресурсоощадності.

Ключові слова: стіновий матеріал; енергоефективність; енергоефективна будівля; теплотехнічний параметр; опір теплопередачі; втрата теплоти; теплонадходження; житловий фонд.