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Iryna Kirakevych, Myroslav Sanytsky, Danylo Kotur

THE EFFECT OF THERMAL INSULATION FROM AUTOCLAVED AERATED CONCRETE ON THE ENERGY PERFORMANCE OF A SINGLE-FAMILY HOUSE

Lviv Polytechnic National University,
Department of Building Production
iryna.i.kirakevych@lpnu.ua

The article examines the effect of thermal insulation from autoclaved aerated concrete on the energy characteristics of a single-family house. Analysis of mathematical models of energy characteristics of external enclosing structures of buildings depending on the thickness of AEROC autoclaved concrete products according to the criteria of heat loss shows that the thermal resistance value of 7.11 m^{2}K/W and the heat transfer coefficient of 0.141 W/(m^{2}K) are achieved using the wall block AEROC D 300 and AEROC Energy thermal insulation panel with a thickness of 200 mm. These indicators correspond to the passive house standard for thermal resistance (Ro ≥ 6.7 m^{2}K/W) and heat transfer coefficient (Uo ≤ 0.15 W/m^{2}K) of external walls, which confirms the feasibility of using AEROC Energy D 150 thermal insulation panels in combination with wall blocks AEROC D 300 for housing construction according to passive construction standards.

Key words: structural insulation aerated concrete, AEROC Energy D 150 insulation panels, thermal resistance, heat transfer coefficient, exterior walls, passive house.

Introduction

The residential and communal sector is responsible for almost 40 % of global CO_2 emissions (Lorenzo, Barozzi, Bellazzi & Danza, 2019). To achieve the goals of the Paris Agreement, the construction sector needs to ensure zero net carbon emissions by 2050 (Högberg, 2013). Ukraine's ambitious goal of achieving climate neutrality cannot be achieved without significant changes in buildings that drastically reduce energy demand and greenhouse gas emissions (Pedroso, Brito & Silvestre, 2019). To achieve this goal, almost all buildings in Ukraine need to be modernized. The practical implementation of such a complex task requires the expansion of the scale of thermal modernization of buildings and an increase in the pace of their implementation (Eleftheriadis & Hamdy, 2018).

In the EU, there is the following classification of buildings according to their energy efficiency (Li, Yang & Lam, 2013):

1. "Old buildings" (buildings before the 1970s) require about 300 kWh/m^2 year for their heating.
2. "New buildings" (those built before 2000) – 150 kWh/(m^2·year).
3. "Low energy consumption buildings" (since 2002, it is not possible to build new buildings according to a lower standard) – 60 kWh/m^2·year.
4. "Passive buildings" (there is a law according to which from 2019 in Europe it is not possible to build buildings to a lower standard than passive buildings) – 15 kWh/(m^2·year).
5. "Zero energy buildings" (buildings that do not require additional energy for heating at all, except for that produced by the building itself) – 0 kWh/(m^2·year).
6. "Energy positive buildings" (that is, those that, with the help of installed solar panels, collectors, recuperators and heat pumps, produce more energy than the building needs) (Norouzi & Nasiri, 2021) .

Designing an energy-efficient house is a complex process that involves a rational choice of thermal protection for building structures, the selection of engineering equipment, and the effectiveness of energy sources (Sanytsky, Sekret & Wojcikiewiez, 2012). Energy efficiency has two aspects. The first aspect is the performance of enclosure structures, which means that the better the thermal insulation material characteristics, the less energy is required to heat the house during the cold season and to condition it during the warm season (Marushchak & Pozniak, 2022). The second aspect is providing the house with cheap energy and its rational use (Torres-Rivas, Pozo, Palumbo, Ewertowska, Jiménez & Boer, 2021). Combining constructive and engineering measures while simultaneously utilizing modern energy-saving technologies is a rational and economically viable way to improve the energy efficiency of a building (Wang, Chiang, Cai, Li, Wang, Chen, Wei & Huang, 2018, Antonelli, Erba & Azambuja, 2020).

To address the pressing issues of energy efficiency, AEROC company offers an innovative insulation system – an environmentally friendly, non-combustible mineral-based thermal insulation with high durability characteristics. The proposed system is a comprehensive approach to addressing insulation issues (Serdiuk, Franishina, Serdiuk & Rudchenko, 2021). The mineral-based and efficient insulation system is designed for external wall insulation during building construction and renovation to reduce energy costs for heating and conditioning of premises, optimize the thermal regime inside premises, and provide decorative finishing of building.

The use of AEROC Energy D 150 thermal insulation panels has several advantages compared to traditional thermal insulation materials. This innovative thermal insulation material is an environmentally friendly, non-combustible, and durable insulation panel made of autoclaved aerated concrete with a crystalline material structure. AEROC Energy autoclaved aerated concrete consists of 90 % air trapped in uniformly distributed pores in the material's crystalline framework. Thanks to the large volume of air in the material's structure, AEROC Energy has a low thermal conductivity. The AEROC Energy D 150 panels are characterized by high thermal and physical properties and operational characteristics that have no analogues among modern thermal insulation materials. The panels are completely non-combustible, have a solid and even surface, stable dimensions, and are easy to install. The wide temperature range of application, resistance to aggressive environments, ultraviolet radiation, and good strength characteristics all confirm the feasibility of using the AEROC Energy D 150 system as a thermal insulation material (Serdyuk & Rudchenko, 2019).

The use of AEROC Energy insulation panels has several advantages compared to traditional insulation materials (Lapovskaya, Dyuzhilova & Demchenko, 2020). In particular, AEROC Energy D 150 insulation panels based on autoclaved aerated concrete with an average density of D 150 have a thermal conductivity of $\lambda = 0.055$ W/(m·K), vapor permeability of 0.3 mg/(m·h·Pa), dimensional stability, non-flammability, and a maximum operating temperature of up to 600 ºC. The effective working life of AEROC Energy D 150 insulation panels is about 100 years, which is advantageous compared to traditional polystyrene and mineral wool insulation materials with an operating life of approximately 10–25 years and up to 30 years, respectively. An important advantage of this system is its cost-effectiveness, with external insulation installation costing 20–30 % less than when using mineral wool or polystyrene foam. The service life of AEROC Energy D 150 panels is up to 100 years, while for EPS polystyrene foam it is up to 15 years, and for mineral wool it is up to 30 years (Rudchenko & Serdyuk, 2021). Another advantage of AEROC Energy D 150 thermal insulation panels is their ecological safety compared to polystyrene foam, which releases toxic substances when heated, and mineral wool, which can be a source of hazardous dust. In addition, AEROC Energy D 150 thermal insulation panels are biostable and do not disintegrate under the influence of ultraviolet radiation, withstand high temperatures without releasing toxic substances, which allows these materials to be classified as the safest in construction. The high water vapor permeability of this material ensures good air quality and a pleasant microclimate in rooms.

The aim of this study is to investigate the impact of efficient thermal insulation made of autoclaved aerated concrete on the energy characteristics of a single-family house.

Techniques used

The research object is an individual residential house with walls 300 mm thick made of AEROC D 300 autoclaved aerated concrete (thermal conductivity in dry state 0.08 W/m.K, compressive strength more than 0.4 MPa, calculated moisture content in operation conditions is 6–8 %). The outside of the house is insulated with AEROC Energy D 150 aerated concrete panels with the following technical characteristics: thermal conductivity at 25 °C not exceeding 0.055 W/(m·K); coefficient of water vapor permeability – 0.3 mg/(m·h·Pa); compressive strength at 10 % deformation not less than 0.4 MPa; maximum operating temperature – 600 °C.

The calculation of the main thermal performance indicators of enclosing structures to confirm their compliance for energy-efficient buildings was carried out in accordance with DSTU 9191:2022. To optimize the thermal characteristics of the external walls of an individual house to improve energy and environmental indicators and obtain maximum economic efficiency, a mathematical experiment planning (Tabl. 1) was carried out. The average density of the AEROC autoclaved aerated concrete material for the external wall (X1 = 300, 400 and 500 kg/m^3) and the thickness of the AEROC Energy D 150 external insulation panels (X2 = 100, 150 and 200 mm) were selected as the variable parameters.

Table 1

Planning matrix and results of a complete two-factor experiment

$N_{o.}$	X_1	X_2	The average density of the load-bearing wall, ρ, kg/m^3	Insulation thickness, δ, mm	Thermal resistance, R, m^2·K/W	Heat transfer coefficient, U, W/(m^2·K)
1	+1	+1	500	200	6.03	0.166
2	+1	-1	500	100	4.24	0.236
3	-1	+1	300	200	7.11	0.141
4	-1	-1	300	100	5.29	0.189
5	+1	0	500	150	5.15	0.194
6	-1	0	300	150	6.20	0.161
7	0	+1	400	200	6.35	0.157
8	0	-1	400	100	4.53	0.221
9	0	0	400	150	5.44	0.184

The obtained results confirm the feasibility of using AEROC Energy D 150 aerated concrete panels (with an average density of 150 kg/m^3) as insulation for the main wall made of AEROC D 300 aerated concrete with an average density of 300 kg/ m^3. Thus, according to the values of the normative thermal resistance (R_{pr} =7.11 m^{2}K/W > $R_н$=4.0 m^{2}K/W), the optimal combination in the external enclosing structure is the use of a 300 mm thick AEROC D 300 aerated concrete main wall and 200 mm thick AEROC Energy D 150 insulation panels (Fig. 1).

The obtained results of calculating the regression coefficients are shown in the Table 2.

Table 2

Coefficients of regression equations

Functions feedback	Regression coefficients					
	b_0	b_1	b_2	b_{12}	b_{11}	b_{22}
Y_1	5.443	-0.530	0.905	-0.008	0.230	-0.005
Y_2	0.184	0.018	-0.030	-0.005	-0.006	0.005

Analysis of the given coefficients allows for several technological conclusions to be made, including that positive signs of coefficients b_2 and b_{11} indicate a positive influence of increasing insulation thickness on thermal resistance values (Y_1, m^2K/W). The maximum thermal resistance value of 7.11 (m^2K)/W is achieved when using the AEROC D 300 wall block with an average density of 300 kg/m3 and the AEROC Energy D 150 insulation panel with a thickness of 200 mm. Analysis of the isoparametric surface of the heat transfer coefficient changes depending on the thickness of the AEROC Energy D 150 gas concrete insulation and the average density of the AEROC gas concrete main wall, as well as coefficients b_1 and b_{22} in the heat transfer coefficient equation (Y_2, W/m^2K), suggests that maximum insulation thickness ensures minimal heat transfer coefficient values at 0.141 W/m^2K. These indicators correspond to the passive house standard regarding thermal resistance ($Ro \geq 6.7$ m^2K/W) and heat transfer coefficient ($Uo \leq 0.15$ W/m^2K) of external walls.

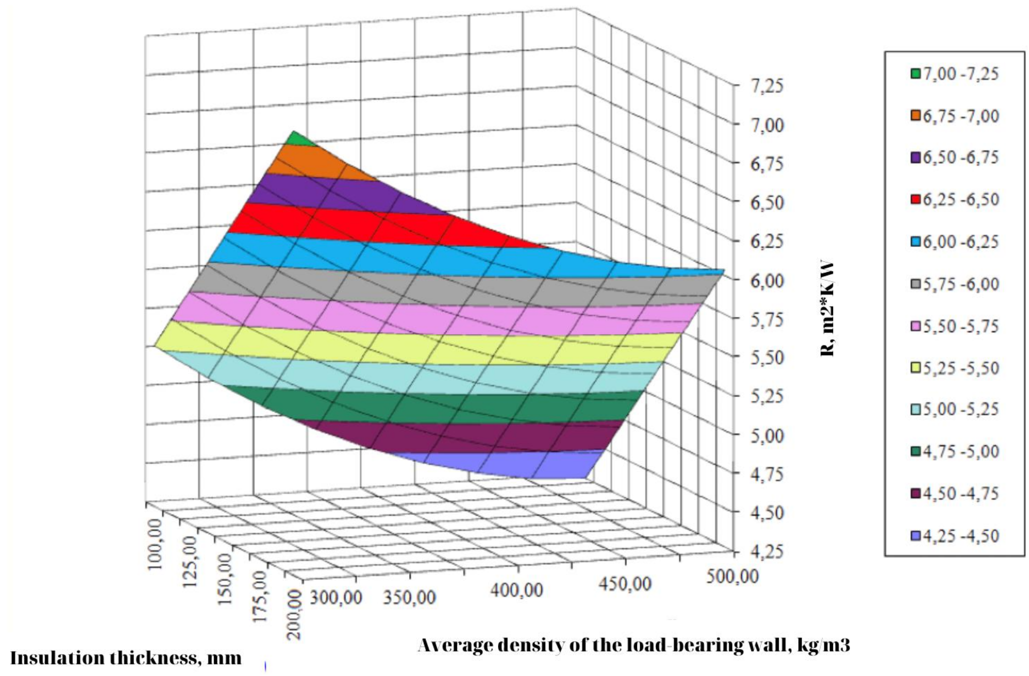

Fig. 1. Isoparametric surface of changes in thermal resistance depending on the thickness of aerated concrete insulation AEROC Energy D 150 and average density aerated concrete main wall AEROS D 300

The optimal solution for the technology of constructing external walls from autoclaved aerated concrete can be the laying of blocks of AEROC D 300 structural insulation concrete with a thickness of 300 mm, with insulation of AEROC D 150 porous insulation concrete with a thickness of 200 mm, which meets the requirements of the energy-efficient building standards for external walls. For a typical single-family house with a total area of 120 m^2 and an external wall area (opaque part) of 150 m^2, the heat loss through the walls is 1780 kWh per year, which is an order of magnitude lower than that of a traditional ceramic brick wall with a thickness of 0.40 m. As a result, it creates the possibility of implementing low-energy building standards for passive houses, for which the heat consumption for heating is less than 15 kWh/(m^2 per year). In summary, using the combination of AEROC D 300 and AEROC D 150 in constructing external walls can help meet energy-efficient building standards and reduce heat loss through walls, allowing for the possibility of implementing low-energy building standards for passive houses.

Conclusion

Thus, the design decisions involving the use of AEROC Energy D 150 autoclaved aerated concrete concrete provide the opportunity to quickly, reliably, and affordably build a warm and environmentally-friendly home on a small plot of land that meets the needs of a modern family. The AEROC Energy insulation system solves the problems of high durability, sufficient sound insulation, fire and environmental safety, vapor permeability, and architectural expression, allowing for the creation of a strong facade capable of withstanding strong mechanical loads and providing high thermal insulation for comfortable living, while also meeting the highest requirements for the construction of energy-efficient and passive houses.

Prospects for further research

The use of AEROC Energy D 150 heat-insulating panels based on autoclaved aerated concrete of average density D 150 in a complex with AEROC D 300 aerated concrete blocks for the construction of building enclosures will contribute to the design of buildings with zero energy consumption, which is a priority direction of the low-carbon development strategy.

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І. І. Кіракевич, М. А. Саницький, Д. Р. Котур
Національний університет “Львівська політехніка”,
кафедра будівельного виробництва

ВПЛИВ ТЕРМОІЗОЛЯЦІЇ З АВТОКЛАВНОГО БЕТОНУ НА ЕНЕРГЕТИЧНІ ХАРАКТЕРИСТИКИ ОДНОСІМЕЙНОГО БУДИНКУ

Досліджено вплив ізоляції з теплоізоляційного та довговічного матеріалу на основі автоклавного газобетону на енергетичні характеристики односімейного будинку. Широкий температурний діапазон застосування, достатньо високі показники міцності, простота монтажу – все це визначає доцільність використання системи ізоляційних панелей AEROC Energy як теплоізоляційного матеріалу.

Моделювання параметрів теплоізоляційної оболонки житлових будівельних об’єктів дало змогу встановити показники зовнішніх огороджувальних конструкцій, які відповідають нормованому мінімальному рівню енергоефективності стандарту пасивного будівництва. Оптимальним вирішенням технології будівництва зовнішніх стін з автоклавного газобетону може бути укладання блоків конструкційно-теплоізоляційного бетону AEROC D 300 товщиною 300 мм з утепленням теплоізоляційним пористим бетоном AEROC Energy товщиною 200 мм, що забезпечує вимоги стандарту пасивних будинків до зовнішніх стін. Для типового односімейного будинку загальною площею 120 м^2 з площею зовнішніх стін (непрозорої частини) 150 м^2 втрати теплоти через стіни становлять 1780 кВт*год, що на порядок менше порівняно із стіною з повнотілої керамічної цегли. За товщини утеплювача на рівні 200 мм забезпечуються мінімальні значення коефіцієнта теплопередачі (0,141 Вт/м^{2}К). Отримані теплоенергетичні показники відповідають стандарту пасивного будинку щодо термічного опору (Ro $\geq$ 6,7 м^{2}К/Вт) та коефіцієнту теплопередачі (Uo $\leq$ 0,15 Вт/м^{2}К) зовнішніх стін.

Застосування теплоізоляційних панелей AEROC Energy D 150 на основі автоклавного газобетону марки за середньою густиною D 150 в комплексі з газобетонними блоками AEROC D 300 для спорудження огороджувальних конструкцій будівлі сприяє проєктуванню будинків з нульовим споживанням енергії, що є пріоритетним напрямком стратегії низьковуглецевого розвитку.

Ключові слова: автоклавний газобетон, теплоізоляційні панелі AEROC Energy D 150, термічний опір, коефіцієнт теплопередачі, зовнішні стіни, пасивний будинок.